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BULLETIN G 7

Glacial Deposits
Outside the Wisconsin Terminal Moraine
in Pennsylvania

By

FRANK LEVERETT

(Prepared in cooperation between the United States Geological Survey and the Pennsylvania Topographic and Geologic Survey)

Department of Internal Affairs
PHILIP H. DEWEY, *Secretary*
Topographic and Geologic Survey
GEORGE H. ASHLEY, *State Geologist*

Harrisburg, Pa.

1934

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LETTER OF TRANSMITTAL

To the Honorable Philip H. Dewey,
Secretary of Internal Affairs

Sir:

I have the honor to transmit herewith and to recommend for publication, a bulletin on the Glacial Deposits of Pennsylvania outside the Wisconsin Terminal Moraine, by Frank Leverett.

The manuscript for this bulletin has been in our files for a number of years awaiting funds for its publication. At the present time funds are available sufficient to cover the cost of this small bulletin, but not sufficient to cover the printing of several larger bulletins now on hand.

This bulletin deals with a subject practically new, in so far as the material submitted is concerned, and a subject that has proved in several instances—notably in Wisconsin and Michigan—to have very large economic interest, as the mapping of these deposits has often been of service in the study of water resources and soils, in locating material for road and other construction, and for other incidental uses, quite aside from the widespread interest of the schools and intelligent people generally in the history of glacial advances in this State and in the deposits left on their retreat.

Respectfully submitted,

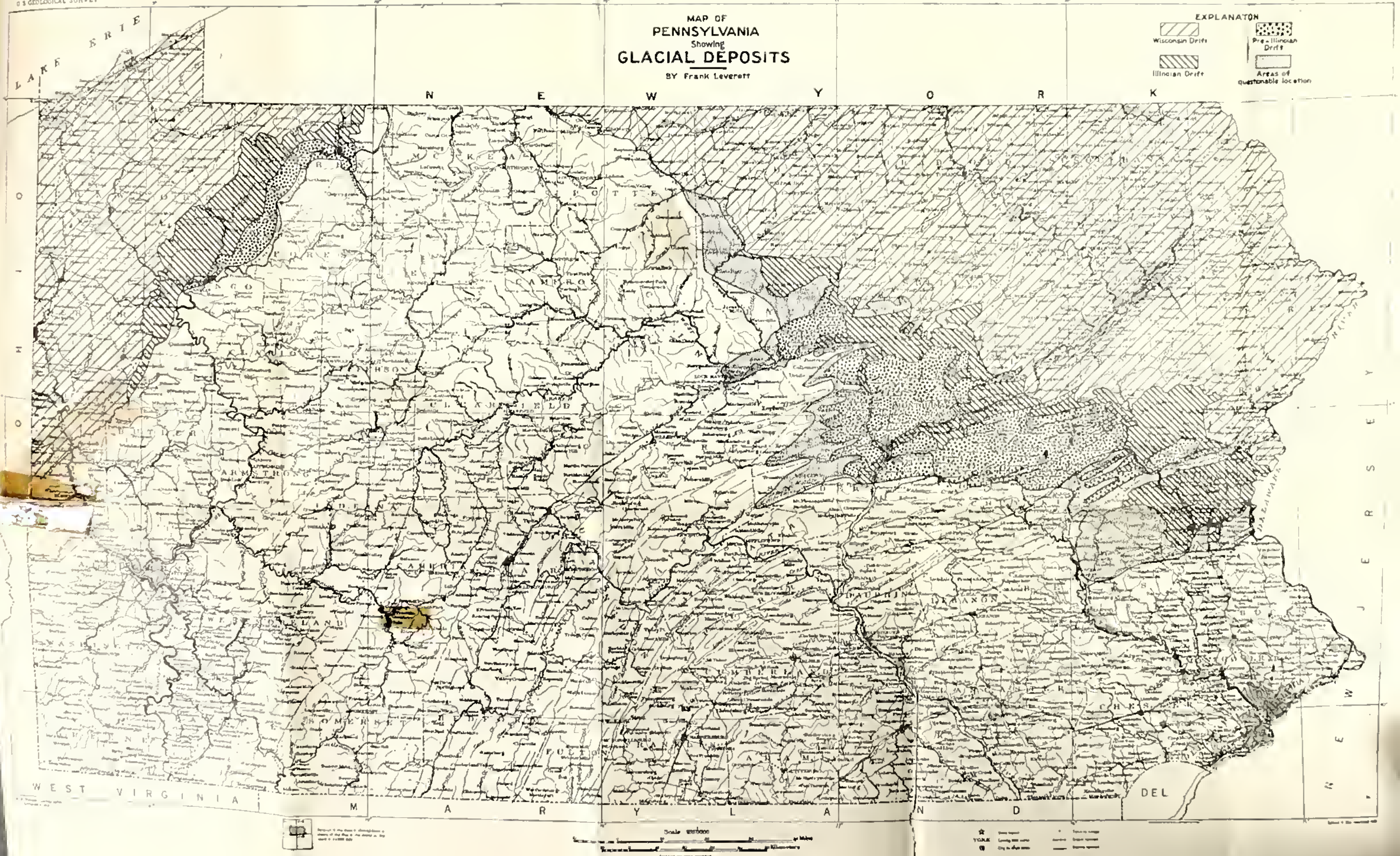
Geo. H. Ashley

April 20, 1934. *State Geologist.*

DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

PLATE I

STATE OF PENNSYLVANIA



MAP OF
PENNSYLVANIA
Showing
GLACIAL DEPOSITS
BY Frank Leverett

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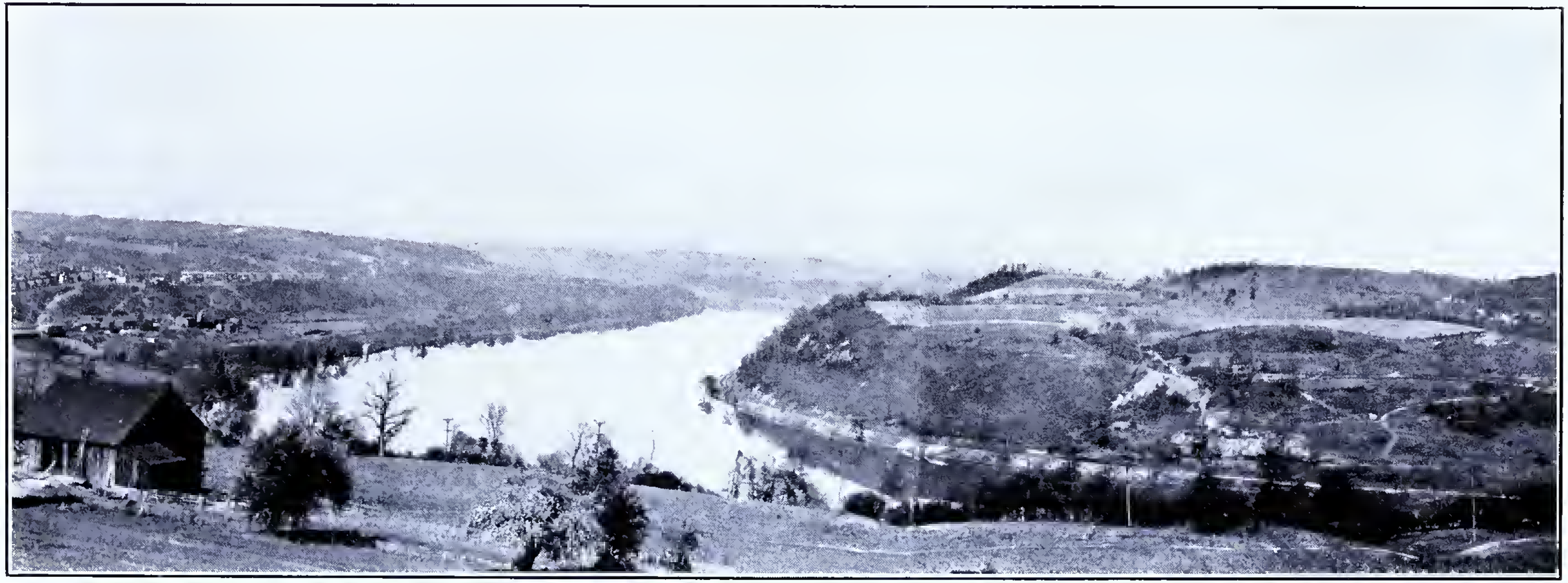
Plate II



Allegheny River below Ford City; Cadogan at extreme left. The terrace directly across the river and that at Cadogan are covered with gravels of Illinoian age. The railroad below Cadogan is on a terrace of Wisconsin age.

Glacial Deposits Outside the Wisconsin Terminal Moraine in Pennsylvania

By Frank Leverett

HISTORY OF FIELD STUDIES

PRESENT INVESTIGATION.

The investigations by the present writer on which this report is based were made in the field seasons of 1926, 1927, and 1928 under a cooperative arrangement between the United States Geological Survey and the Pennsylvania Geological Survey. Attention has been directed chiefly to the older or pre-Wisconsin drifts, though some revision of the border of the Wisconsin drift was made where it was found to be different from the mapping by H. Carvill Lewis as given in Report Z of the Pennsylvania Second Geological Survey. The report includes a discussion of the pre-Wisconsin drifts exposed in New Jersey with those of eastern Pennsylvania, in order to bring out more clearly the general ice movements of the region. It aims also to explain certain differences of interpretation of these drifts that appear in the literature.

In addition the gravel deposits of the Susquehanna Valley of all ages were given attention and the relation of each level of gravel deposition to the sheets of glacial drift was made a subject of detailed study. Some notes were made also on their relation to the gravels of the Atlantic Coastal Plain. In that connection conferences were held with several persons who have been working on the Coastal Plain formations, viz. M. R. Campbell, L. W. Stephenson, George W. Stose. C. Wythe Cook, Mrs. Eleanor Bliss Knopf, and Miss Anna I. Jonas. Field conferences were also held from time to time with George H. Ashley on various phases of the work, and with H. B. Kümmel on the work in New Jersey.

EARLIER STUDIES, 1840-1880.

1840. Louis Agassiz announced after prolonged studies of the Swiss glaciers that large parts of North America and Europe had been covered by glacial ice. For many years before this geologists had observed the drift and striae in the Northeastern States and before 1840 several geologists had expressed doubt that these features could have been made by water even though it carried floating ice. Even as early as 1817, Daniel Drake concluded that icebergs must have been present in Ohio.

1850-1851. J. P. Lesley of the Pennsylvania Geological Survey and Professor Edward Desor of Switzerland studied the evidence of glaciation in the State and Lesley concluded that the ice had reached as far south as Dauphin County*.

1858. Henry D. Rogers described briefly, the "Great Boulder Drift," noted its southern limit across Pennsylvania but made no mention of ice or glaciers.

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*Lewis, H. C., Report on the Terminal Moraine in Pennsylvania and Western New York; Pa. Second Geol. Survey, vol. Z, p. xli.

1870-1880. During this period the Second Geological Survey of Pennsylvania was established under J. Peter Lesley and there followed many notes and descriptions of what is now called the Wisconsin drift as well as observations on the evidences of glacial action outside the area of the Wisconsin drift. It is this latter matter that particularly interests us here. Of special interest are the observations of George H. Cook of New Jersey, Chas. E. Hall and F. Prime, Jr. Professor Cook had mapped the limits of this drift in New Jersey and as far west in eastern Pennsylvania as the place where it crosses Blue Mountain. The results appear to have been first announced in a paper entitled "On the southern limit of the last glacial drift across New Jersey, and the adjacent parts of New York and Pennsylvania," read at the Wilkes-Barre meeting of the American Institute of Mining Engineers in May, 1877. This paper, together with a map showing the course of the terminal moraine across New Jersey, was published in 1879[1]. Professor Cook gave a brief outline of the course of the moraine in his annual report for 1877 and included a description of the moraine in his annual report for 1880. The greater part of the description given in 1880 is incorporated in Report Z of the Pennsylvania Second Geological Survey, pages 243-269.

In his paper read at Wilkes-Barre Professor Cook stated that the failure to recognize the moraine earlier had probably been due to the occurrence of surface boulders south of it and of deposits of gravel and boulders considerably to the south of this line. In his report[2] for 1880 (pp. 87-97), he discussed these deposits, and referred to them as older than the deposits of the terminal moraine. Some details of his description are given later.

Mr. Hall described the evidence of extramorainal drift at Lehigh Gap in 1875 in a communication to the American Philosophical Society.

In Report DD of the Pennsylvania Second Geological Survey published in 1878 (pp. 75-77), Mr. Prime argued that deposits in Lehigh County were laid down by the ice sheet. Boulders were noted at all heights from the bed of Lehigh River up to the tops of the slate hills, some of which boulders carried glacial grooves, and most of which were water worn. He also noted a striated outcrop, but did not give its location. That water alone was not the transporting agent was inferred from the lodgment of boulders on prominent ridges as well as along the valleys. Prime seems, however, to have included in the supposed glacial boulders the rock masses on the slope of Kittatinny Mountain many of which are in process of creeping down the slope from ledges near the crest. But he noted that boulders occur sparingly across the entire interval between the Kittatinny Mountain and South Mountain, on the limestone lowland as well as the slate hills.

In 1879 Prime presented a paper before the American Philosophical Society outlining the course of the outer moraine of Wisconsin drift across Northampton County, and of a "glacial moraine"[3] in the Saucon Valley south of Lehigh River near Bethlehem which is now identified by the present writer as a moraine of Illinoian drift. Reference was made to deposits of glacial gravel or "modified drift" at Easton and

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[1] Am. Inst. Min. Eng. Trans., vol. 6. pp. 467-470, 1879.

[2] Cook, George H., Annual report of the State Geologist for the Year 1880: Geological Survey of New Jersey, 1880.

[3] Proc. Am. Phil. Soc., vol. 18, p. 85, 1879.

West Bethlehem, at an altitude of about 320 feet A. T., which were interpreted to have been derived from till. Their occurrence at similar altitude at points 14 miles apart was taken to suggest a water body of that height, and this idea was further developed by Lesley in the discussion of Prime's paper, who cited the presence of gravel deposits at that height near Philadelphia, and stated that Persifor Frazer had noted "drift gravel" in two patches in Lancaster County some miles back from the Susquehanna River, and distant from each other. It appeared to him probable that they were all due to a higher stand of the sea. That the several deposits might be of widely different age and origin was not suggested.

1880-1884. The tracing of the ~~course~~ of the Wisconsin terminal moraine across Pennsylvania was begun by H. Carvill Lewis in December, 1880, and carried through the entire field season of 1881. For six weeks he was accompanied or assisted by G. Frederick Wright. Some parts of the line were revisited by Lewis in 1882, and his report (Report Z of the Pennsylvania Second Geological Survey) was submitted in October, 1882, as a "Report of Progress," and was published in 1884. It was called a reconnaissance report by Lesley as well as by Lewis, that should not be taken as "a complete and finished portraiture even of the line of the Terminal Moraine, much less of the glaciated region behind it to the north, or of the unglaciated region in front of it to the south." Subsequent studies have shown that the mapping by Lewis and Wright, though not marking the limits of glaciation as now understood, is in the main a correct mapping of the limits at the Wisconsin stage. As indicated below there are a few places where outlying Illinoian drift is mapped with the Wisconsin.

For several years after the appearance of Report Z there seems to have been a general acceptance of the view that the "Terminal Moraine" traced by Lewis and Wright marks the full limit of the ice sheet, the features outside that had been referred to glacial action being referred to water action, either contemporaneous with the glaciation, or of earlier date. The mapping by Lewis and Wright seems also to have caused I. C. White to explain the outlying drift deposits of Columbia, Montour, and Northumberland counties as the product of flooded rivers, and to have influenced Lesley in adopting the same view.

In 1880 John F. Carll, in volume III of the Second Geological Survey, described glacial phenomena in northwestern Pennsylvania, especially the evidences for valley deepening and drainage changes. He recognized and traced in some detail the preglacial courses of several of the rivers in contrast with their present courses, noting from well records the old gradient of now-hidden channels of the older streams.

1883. Pennsylvania Second Geological Survey county reports covering the Susquehanna Valley usually give the Pleistocene deposists scanty treatment. Those by I. C. White in volume G 7, however, are not so deficient. They embrace six counties, Wyoming, Lackawanna, Luzerne, Columbia, Montour, and Northumberland, lying east of the West Branch of Susquehanna River. Wyoming and Lackawanna counties and nearly all of Luzerne County are within the limits of the Wisconsin drift, and this drift extends into the eastern part of Columbia County, but the greater part of Columbia and all of Montour and Northumberland lie outside its limits. In these counties an old drift, with boulders of all sizes and degrees of angularity, was found to be widely prevalent, but White was unable to find striated rock ledges there such as are commonly present within the limits of the Wisconsin drift. So he interpreted this drift to have been laid down in "flooded rivers" outside the limits of the ice sheet. But he recognized that there were difficulties in applying this interpretation, as indicated in the passages quoted below.

After noting the presence of abundant drift material in a lowland extending west from Fishing Creek to the West Branch of the Susquehanna along the line of the Milton and Watsontown anticlines, he says (G 7, p. 18):

> In view of all the facts in hand it seems to me probable that these boulders were transported by floating ice and other means in a great lake-like river which flowed westward from the *Terminal Moraine* (at the eastern line of Columbia County) during a *flooded river epoch*, when hills now rising 800-900 feet A.T., were submerged.
>
> That this sheet of water was an actual river seems proven by the great boulder deposit which it made at its junction with the West Susquehanna, at the northern line of Northumberland County; for there a great bluff of transported boulders 175 feet high extends along the east bank of the river for nearly two miles. The upper limit of these boulders along the northern line of Northumberland County is about 800 feet A.T.

On page 217 the following remarks are made as to the drift near Orangeville, on the south side of Huntington Mountain:

> Great heaps of *rounded boulders* are scattered over the highest hills in the portion of this township east and south of Big Fishing Creek, up to 950 feet A.T. They look like genuine drift heaps; but Professor Lewis is confident the *ice* did not come this far west, and I could not find any evidence of glaciation in the rocks themselves or the underlying beds. Some of the boulders are angular and 2 to 3 feet in diameter. They belong mostly to the Pocono and Catskill series. If not transported to their present position by the *ice sheet* they form an important link in the chain of evidence that the sea-level once stood at least 1,000 feet above its present datum.

On page 248, under the heading "Drift" the following remarks are made:

> *Drift.* A little east of Mr. Charles Eck's, the gravel and boulder deposits which fill the old Hamilton buried valley (running westward to Danville) are seen extending up to a level plain at 615 feet A.T. or 165 feet above the Susquehanna River, at the mouth of Fishing Creek, one mile east. In these deposits are found small rounded boulders of *granite*, *gneiss*, and other *igneous rocks.*

Concerning boulders on the crest of a ridge north of the Susquehanna east of Bloomsburg the following remarks are made (p. 256):

> In passing south from Light Street vast heaps of rounded *Pocono, Catskill, Chemung,* and other boulders occur up to the summit between Fishing Creek and the Susquehanna River at 675 feet A.T. at J. W. Vanderslice's. These transported boulders are also seen as we go eastward along the crest of the Montour ridge, up to 800 feet A.T., many of them resting on the highest summits. Some are angular and 2 to 4 feet in diameter.

Boulders in Center Township, Columbia County, on the crest of Montour ridge, called out the following (p. 263):

> One of these *Pocono* boulders 5 feet in diameter is seen in a field just east from Mr. E. Hutchinson's at 725 feet A.T. No traces of *glacial action* can be seen on the surfaces of the rocks exposed in this township, and yet these large angular boulders lying about on the highest summits look very much as though they had been transported by such agency.

Further remarks concerning the drift in this township are made on page 265:

> *High boulder deposits.* These boulders occur here at 1,000 feet A.T., and the huge piles of them just east of Mr. Remley's near the new church certainly recall the appearance of glacial moraine. Since the ice is known to have come as far west as the next township to the east it looks as if a lobe of it passed along the base of Huntington Mountain and transported the great heaps of rounded and angular boulders which are scattered over the Catskill plateau in this township.

Under the heading "*High drift,*" deposits on a tableland south of the Susquehanna Valley near Catawissa are discussed (p. 291):

> *High drift.* Such boulder deposits occur on the summit of the ridge at the cemetery near Mr. J. John's (2 miles south of Catawissa), where great heaps of rounded boulders of *Pocono* and *Pottsville conglomerate* are seen at 950 feet A.T. With these are many boulders of *Catskill;* and also much sand and finer trash. This locality is on the highest part of the dividing ridge between the Susquehanna and Roaring Creek. I could find no evidence of *Glacial action.*

The following remarks are made concerning the extensive drift deposits in the northern part of Northumberland County (pp. 326-327):

> The entire area, south from this *Chemung plateau* gives evidence of submersion, most probably during the *Flooded river epoch,* for everywhere we find a thick deposit of transported boulders and other trash which must have been carried by running water in some manner since no evidence of *Glacial transportation* could be found. These boulders consist largely of *Pocono and Catskill sandstones,* with a frequent admixture of local rock, the most of the former rounded, but angular ones being occasionally seen. They usually rest in an admixture of clay, sand, and muddy trash, and may possibly have been dropped from floating ice which, breaking off from the terminus of the northeastern glacier, carried the material of the *Terminal Moraine* over the areas submerged by the subsidence of the *Flooded river epoch.* They occur on the summits of the highest hills (about 700 feet A.T.) all over the *Hamilton, Lower Helderberg,* and *Salina valleys.* The exact upper limit of their distribution was not determined in this township (Lewis), though they are not found on the Chemung hills which range in elevation from 900 to 1,200 feet A.T.

Concerning drift on the uplands back of Northumberland the following remarks are made (p. 335):

> Fragments of a hard yellowish-gray sandstone are scattered over the surface all along the southern slopes of Montour ridge and even over the *Chemung hills* to the south. They have come from the *Clinton lower olive beds* at the summit of Montour ridge. There is some mystery connected with the transportation of these boulders, all of which are angular, and not water worn. Boulders of yellowish-gray sandstone, iron sandstone, and others of the *Clinton beds* occur on the summits of the Chemung hills at 800 feet A.T. while a broad valley 200-300 feet lower separates these hills from the source of the boulders on Montour ridge. No evidence of *Glacial action* is to be seen.

On page 363 are notes on boulders back of Selinsgrove Junction on the east bluff of the Susquehanna at 625 feet A. T. or over 200 feet above the river at what now appears to be the southern limit of the ice in the Illinoian stage of glaciation. The boulders are principally sandstone, with "Iron sandstone" from the Clinton, and chert from the Lower Helderberg. Nothing but angular fragments of the country rock could be found there above 625 feet A. T., "so that 215 feet above the river seems to be the highest point reached here by the true *Drift.*"

Report G 7 was published in 1883, a year in advance of Report Z by H. Carvill Lewis on the Terminal Moraine, but it appears that the

Director of the Pennsylvania Geological Survey, J. P. Lesley, took the mapping by Lewis to be the final word as to the extent of the ice sheet in that State, and did not favor any dissent from that opinion on the part of his associates on the Geological Survey, though some years earlier he had considered it probable that the limits of the ice sheet were a considerable distance outside the Wisconsin Terminal Moraine mapped by Lewis. Thus in Report D published in 1875, Lesley refers to the finding of a moraine at Franklin, New Jersey and remarks (p. 67):

> And this spring (1875) Mr. Chance has mapped what seems to be a similar moraine behind the Lehigh Water Gap; near where Mr. C. E. Hall has just found (July 10, 1875) the evident work of glacial ice, pushing all the (Clinton) slates towards the gap; and upon the broken edges lies a genuine top dressing of glacial clay and boulders (till).

The presence of till north of the Lehigh Water Gap was also mentioned by I. C. White in Report G 6, published several years later, and the deflection of Aquashicola Creek into a new course near its mouth was referred by him to the blocking of the old valley by glacial deposits. It thus appears that glacial deposits many miles outside the Wisconsin terminal moraine were thought to be a direct deposit of the ice sheet and classed as till by the Director of the Pennsylvania Second Geological Survey.

In a comprehensive discussion of the coastal formations of the middle Atlantic slope, presented by W J McGee in the *American Journal of Science* in 1888, deposits outside the Wisconsin terminal moraine in the Susquehanna and Delaware valleys were referred to a marine submergence. He put the transition from fluvial to estuarine conditions at 500 feet on the Susquehanna, 400 feet or more on the Delaware, and perhaps 275 feet on the Schuylkill, and 245 feet at the head of Chesapeake Bay*. But he differentiated these deposits from the trains of glacial gravel that head in the Wisconsin terminal moraine and gave the former the name Columbia Formation. He noted the presence of stones of glacial derivation, but he referred the deposits to a glacial stage long anterior to that of the Wisconsin ice invasion (p. 382). He appears, however, to have restricted the earlier ice sheet to limits farther north than the Wisconsin terminal moraine, though he cites the presence of erratics at altitudes higher than the levels given for the marine or estuarine submergence. It now appears that the deposits bordering the Susquehanna and Delaware for some distance outside the Wisconsin terminal moraine were laid down directly by the Illinoian ice sheet, as indicated below.

LATER STUDIES OF EXTRAMORAINIC DRIFT, 1891-1920.

1891. Interest in the Pleistocene deposits outside the Wisconsin terminal moraine was renewed in 1891 when R. D. Salisbury began the study of these deposits in New Jersey, under the auspices of the New Jersey Geological Survey. The following year A. A. Wright took up an independent study of these deposits in that State, while G. Frederick Wright worked in Pennsylvania as well as New Jersey. In 1893 E. H. Williams, Jr. of Lehigh University, and his students, began an inquiry into the extent and age of deposits outside the moraine in

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* Am. Jour. Sci., 3rd ser. vol. 35, p. 381. 1888.

Pennsylvania, that was carried on for about three years. The work by Salisbury and his assistants extended over a period of ten years, and covered the non-glacial as well as glacial deposits of New Jersey. The studies by G. F. Wright and by E. H. Williams are of pertinence to the present discussion, as they embrace deposits in the Susquehanna drainage basin. Salisbury made only incidental reference to the extramorainic glacial deposits in Pennsylvania in connection with his discussion of New Jersey drift. He mentioned the occurrence of striated rock material near Sunbury, Pennsylvania at an elevation between 500 and 600 feet above the Susquehanna River, and at several hundred feet above Lehigh River in the vicinity of Bethlehem, Pennsylvania[1].

1892. At the Rochester meeting of the American Association for the Advancement of Science in 1892 G. F. Wright presented a paper entitled *The Extramorainic Drift of the Susquehanna Valley*, an abstract of which was published in the *American Geologist* as follows:[2]

> The extreme advance of the ice sheet is held to be marked in the Susquehanna region by a thin mantle of drift with plentiful boulders, extending to a distance of several miles in front of the conspicuous belt of hilly drift denominated the terminal moraine. In tracing the moraine through Pennsylvania, the author, with the late Professor Henry Carvill Lewis, named this extramorainic drift a "fringe" believing its deposition to have been nearly contemporaneous with the accumulation of the morainic hills. Terraces of stratified drift deposits, with infrequent boulders, occurring farther south along the Susquehanna, which have been regarded by McGee as evidence of a marine submergence changing the valley to an estuary, are thought instead to be of fluvial origin, belonging to a time when the land there was slightly depressed, but not to the sea level, near the close of the Glacial period.

In the discussion following the reading of this paper Salisbury objected to the term "fringe" because this extramorainic drift was referred by him, as also by McGee and others, to an earlier epoch of glaciation, apparently several times as long ago as the Wisconsin glacial stage when the moraine was formed.

In December, 1892, Wright presented a paper before the Philadelphia Academy of Sciences on the "Extramorainic Drift in the Susquahanna, Lehigh and Delaware Valleys"[3]. He expressed the view that glaciation extended down the Susquehanna Valley about to Bloomsburg, covering land 300 to 500 feet above the river. Below there he regarded the deposits up to 200 feet above the river at Selinsgrove and 130 feet at Harrisburg to be more probably due to fluvial action. He noted the presence of granitic pebbles in the deposits at Harrisburg as of great significance, for there are no outcrops of granite anywhere in the watershed of the Susquehanna above Harrisburg. Their deposition, therefore, must be either contemporaneous with or subsequent to the glacial invasion. Wright expressed the opinion that the ice sheet covered the lower part of the Lehigh Valley, and extended beyond its mouth down the Delaware Valley to Riegelsville, or to a distance of more than 20 miles beyond the Wisconsin terminal moraine which crosses the Delaware near Belvidere. He thus was in agreement with Salisbury as to the extent of glaciation in the Delaware

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[1] Bull. Geol. Soc. America, vol. 3, pp. 179-180, 1892.

[2] Am. Geol., vol. X, p. 219, 1892.

[3] Proc. Acad. Nat. Sci. Philadelphia, 484, p. 469, 1892.

Valley, but dissented from the view that the outlying drift is much older than that in the moraine.

In the fifth edition of his volume on the "Ice Age in North America," Wright inserted a brief discussion (pp. 151-158) of the extramorainic drift in eastern Pennsylvania and New Jersey, the main part of the data being taken from papers by E. H. Williams, Jr. published prior to 1910, the year the volume went to press. He maintained with Williams that the evidence of a much greater age than that of the Wisconsin drift is not conclusive.

1893-8. Studies by E. H. Williams, Jr. begun near Bethlehem in 1893 were extended westward into the Susquehanna drainage by 1894. He early became convinced that the ice sheet covered the part of the Lehigh Valley near Bethlehem and extended into Saucon Valley, a southern tributary, as had been reported some years earlier by Prime, as already indicated. The evidence noted was that of erratic pebbles of Oriskany sandstone and other Paleozoic rocks on the slopes of South Mountain up to 600 feet or more. He placed the limit of ponded water at about 500 feet, that being the altitude of the lowest part of the divide between the Lehigh and Schuylkill drainage, and assumed that the waters from the ice sheet drained to the Schuylkill[1]. This glaciation was interpreted to have similar age to that which formed the main terminal moraine traced by Lewis and Wright, the main reasons being (1) the presence of the extramorainic drift at low altitudes in the valleys, (2) the presence of relatively fresh pebbles in the rusty looking drift, and (3) the moderate degree of alteration of rock ledges from which the residuary clay had been removed by the ice sheet. He suggested that the drift had a rusty appearance because of the incorporation of a large amount of residuary clay, rather than because of great age, and referred it to the same glacial stage as the "Terminal Moraine" of Lewis and Wright.

The results of studies by Williams and his assistants in 1894, when the mapping had been carried as far west as Lock Haven in the Susquehanna Valley, were presented in a paper in the *American Journal of Science* in 1895[2]. In a map accompanying this paper the glacial boundary is carried westward along the north slope of South Mountain to the Schuylkill River near Shoemakersville, but is made to double back eastward along the south side of Kittatinny Mountain nearly to the Lehigh Valley. It is represented to protrude westward in the valleys and have reentrants at the ridges from the Kittatinny Mountain northward to Mauch Chunk and then take a westward course near Tamaqua, Morea, Frackville, Ashland, and Shamokin to the Susquehanna Valley below Selinsgrove. A few miles west from the Susquehanna, the boundary turns northward and is represented to protrude in valleys and have reentrants at ridges as far as the vicinity of Williamsport, and then runs westward along the south side of the West Branch of Susquehanna River to the vicinity of Lock Haven.

As the drift is very scanty along much of this border the extent of the ice could not be mapped precisely. Evidence of glaciation was made dependent on "finding fragments of formations moved out of place in a uniform direction, and independent of the slope." Scarcely any material of Canadian derivation was found. The red Mauch Chunk rocks were easily identified and found useful in determining the extent of glacial transportation. In general glaciation was also found to have produced considerable removal of the residuary material and decayed rock from the surface of prominent rock formations, and deposition of such material in the lowlands.

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[1] Extramorainic drift between the Delaware and the Schuylkill. Bull Geol. Soc. America, vol. 5, pp. 13-15, 281-296, 1894. Glaciation in Pennsylvania, Science, vol. 21, p. 313, 1893. The age of the extramoraine fringe in eastern Pennsylvania. Am. Jour. Science, 3rd ser., vol. 47, pp. 34-37, 1894.

[2] Notes on the southern Ice Limit in Eastern Pennsylvania: Am. Jour. Sci., 3rd ser., vol. 49, pp. 174-185, 1895.

Mention is made (p. 180) of an indurated till under the outwash gravel outside the Terminal Moraine of Lewis and Wright near Berwick "so compact that a pick can hardly be driven into it." But ordinarily the extramorainic drift though of rusty appearance is not much indurated. As the border of this drift has a rude parallelism to the course of the Terminal Moraine, Williams uses this as additional reason for its reference to the same glacial stage. He maintains, as in the earlier papers, that the rustiness is due entirely to pre-glacial weathering, and should not be taken as an indication of great age of the drift.

Considerable ponding must have occurred in valleys that drained toward the ice border. A striking evidence of this is found by Williams in the presence of prominent alluvial cones where streams came into the Susquehanna from the south in the section between Williamsport and Lock Haven. One at Jersey Shore was built up to a height of 150 feet above the Susquehanna bottoms, and makes a conspicuous projection into the valley. The amount of slackwater clay remaining in these valleys is slight. Some of the clayey material cited by Williams as a slackwater deposit, has the aspect of ordinary clayey till, and appears to the present writer more likely to have been a deposit beneath the ice sheet than in ponded waters outside the iceborder.

In a communication to *Science* in 1896[1] Williams called attention to the fresh aspect of the surface outcrop of the Mammoth coal bed at Morea, the weathered coal having been removed by glaciation, and that too at a point very near the limits of glaciation. A similar freshness of surface outcrop was noted on slate near Siegfried in the Lehigh Valley. In a paper read before the American Association for the Advancement of Science in 1896, an abstract of which appears in the *American Geologist*[2], Williams cited the freshness of some pebbles found in the extramorainic drift, and called attention to some which had been weathered prior to glaciation and then subjected to glacial planing on one or two sides, so that the weathered parts are worn through. He was led by such features to doubt the great age claimed by some geologists for the extramorainic drift. In this paper he cited evidence that the reentrant angle in the glacial boundary in southwestern New York lies between an eastern and a western ice lobe whose movements were more or less independent, and whose drifts are from widely different sources.

In a paper published in the *Proceedings of the American Philosophical Society in 1898*[3] Williams accepted the terms Kansan and Wisconsin for the extramorainic and the morainic drift, but without grant ing great differences in age. In this paper he interpreted the junction of the two ice lobes that met in southwestern New York to have been farther northeast at the time the extramorainic drift was deposited than when the morainic or Wisconsin drift was laid down. On this interpretation the eastern lobe of the Wisconsin ice extended farther to the southwest in New York and northern Pennsylvania than the limits of the earlier ice movement. Williams has abandoned this view and now holds the view that the border of the extramorainic drift is nearly concentric with the Wisconsin terminal moraine in this reentrant angle[1].

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[1] Science, n. s., vol. 3, pp. 782-783, 1896.

[2] Am. Geologist, vol. 18, pp. 237-238, 1896.

[3] Notes on Kansan drift in Pennsylvania. Am. Phila. Soc., Proc., vol. 37, pp. 84-87, 1898.

In a paper in the *Proceedings of the Wyoming Historical and Geological Society* of Wilkes-Barre, Pennsylvania[2], Williams discussed the effect of the "Kansas Glaciation" on the river system of northern Pennsylvania. The principal effect in the part east of the Alleghenies was found to be the development of large alluvial cones where streams entered waters ponded in front of the ice sheet, there being very little shifting of drainage. But west of the Alleghenies the drainage was greatly modified, and streams that had been tributary to the Lake Erie basin were turned into the Ohio drainage, a feature determined by other geologists some 25 years earlier.

1917. Years elapsed before Williams made further contributions to the literature, but in 1917 he published privately *Pennsylvania Glaciation, First Phase*, a pamphlet of 101 pages, which presents in some detail the results of studies carried on from 1893 to 1896. These results are considered below in connection with the discussion of my own studies. This pamphlet discusses first the main topographic features of the district over which the ice sheet passed to reach Pennsylvania, and their influence in developing a series of lobes and somewhat independent ice currents. Estimates are also given as to the probable thickness of ice required to permit a flow over prominent ridges in its path, these being based upon a rule credited to Louis Agassiz, that "no glacier can cross a ridge unless its thickness at the summit of the ridge is at least one-half the height of the ridge." The easternmost lobe, called the "St. Francis—Connecticut River lobe," did not touch Pennsylvania. The next lobe is called "Champlain-Mohawk-Delaware-Pocono-Shamokin lobe." A split from it, termed "Champlain-Hudson Delaware-Schuylkill lobe," passed down Hudson Valley to Storm King Mountain, then across to the Delaware, and from the Delaware westward on south side of Kittatinny Mountain. An ice current which surmounted Storm King Mountain is thought by Williams to have had two branches, one of which, called the "Champlain-Hudson-Manhattan lobe," extended to the mouth of Hudson River, while the other, called the "Champlain-Hudson-New Haven lobe," passed southeast into Connecticut. The last two lobes did not extend into Pennsylvania. A sixth lobe, called the "St. Lawrence-Black River-Susquehanna lobe," is thought by Williams to have been 75 miles wide at the Pennsylvania boundary and 50 miles at Wilkes-Barre, and to have extended as far southwest as McClure, and to have had drainage from there to the Juniata River. The portion of the ice sheet west of this is called by Williams the "Ontario-Finger Lake-Allegheny Plateau lobe," while the part west of it is named the "Ontario-Genessee-Sinnemahoning lobe." These divisions are made the basis for the descriptions of drift given in the paper, and are referred to as lobes Nos. 2, 3, 6, 7, and 8.

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[1] See Frontispiece Map in *Pennsylvania Glaciation, First Phase*. In a letter to the present writer in June, 1928, Williams stated that he had given up the view that the Wisconsin drift overlapped the border of the extramorainic drift.

[2] Vol. VII, pp. 21-28, 1902.

Williams has a still later paper, published by the American Philosophical Society in 1920, entitled *The Deep Kansan Pondings in Pennsylvania and the Deposits Therein.* It is concerned chiefly with deposits in the Allegheny drainage basin, but refers briefly to the ponding above Williamsport in the West Branch of Susquehanna River and its tributaries. The ponding there is assumed to have reached the height of the divide in Bald Eagle Valley between the Susquehanna and Juniata Rivers, about 1,110 feet A. T. The name Lake Lesley had been applied by him to the ponded water body.* Williams suggested that there may have been temporary pondings of the Susquehanna at a narrow place below Bloomsburg, and at Little Mountain below Selins grove, as a result of obstructions by ice jams and debris lodged in them, but the evidence of such obstructions which is cited seems open to question. The same is true of an inferred blocking of Delaware River below Easton.

EARLIER WORK BY THE WRITER

Previous to undertaking the present studies, the writer had been engaged for many years in a study of glacial phenomena in the Mississippi Valley, extending to western Pennsylvania. The results of these studies affecting Pennsylvania were published in 1902 in U. S. Geological Survey Monograph XLI. Since the time of the earlier work topographic maps on the scale of one inch equals one mile, and with 20-foot contours have become available for much of the area involved. These maps were used in a recent restudy of the Wisconsin boundary in northwestern Pennsylvania. In Monograph XLI the existence of more than one glacial advance in northwestern Pennsylvania was clearly recognized and stated. The evidences for several advances are well displayed in the Mississippi Valley and have long been generally accepted. Likewise, the presence of more than one glacial advance in New Jersey has long been believed. It has remained for the studies here reported to determine and trace the presence and extent of the pre-Wisconsin glacial deposits of eastern Pennsylvania.

These studies in eastern Pennsylvania have brought out a complexity in the extramorainal deposits that may account for and harmonize to some degree the diverse interpretations of previous workers. A considerable part of the outlying drift in eastern Pennsylvania is interpreted to be of Illinoian age but only a small part of that in New Jersey appears to be of that age, most of it being much older. As the Illinoian drift has suffered only a moderate degree of weathering and erosion it is not surprising that Williams, whose most detailed studies were made on that drift, should have emphasized the lack of evidence of great age. Salisbury and his assistants on the other hand were giving most of their attention to the much older drift that is widely displayed in New Jersey and so naturally gave this feature emphasis. Salisbury indeed noted the fresher appearance of the part of the drift in New

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*Am. Jour. Sci., 3rd ser., vol. 49, pp. 183-185, 1895.

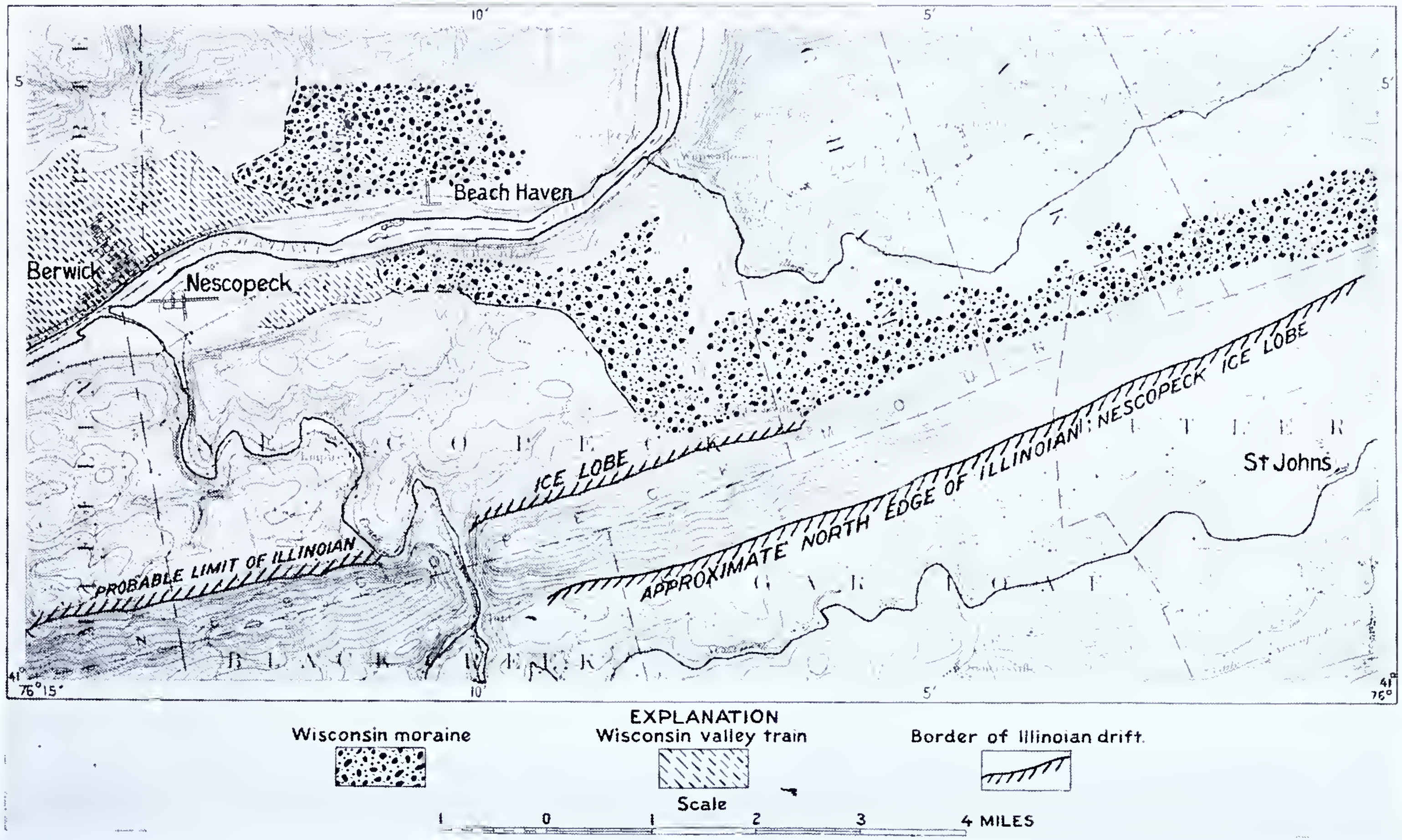


Figure 1. Topographic map of part of Shickshinny quadrangle showing glacial features east of Berwick.

Jersey now considered Illinoian, but he did not reach a definite conclusion as to its age. In view of its position directly outside the moraine he suggested that its fresher aspect might be due to an incorporation of Wisconsin drift with the older drift, which would place it in the Wisconsin stage of glaciation.

A word of explanation seems necessary as to the names applied to the drift sheets in this report. In the Mississippi Basin the first and second drifts, termed the Nebraskan and Kansan, are sheets of considerable thickness. As they are separated by a gumbotil and weathered zone, developed in a long period of deglaciation, they clearly represent two distinct glacial stages. In the district covered by this report there is only a scanty deposit of old drift, which is apparently the product of a single glaciation. It has been named the Jerseyan drift, as it was first clearly brought to notice in New Jersey. As yet it is not satisfactorily determined whether this drift falls in the first or Nebraskan stage, or in the second or Kansan stage of glaciation.

An equivalent of the third or Illinoian drift of the Mississippi Basin seems to be present to the east as well as west of the Alleghenies, and is here discussed under that name. The last or Wisconsin drift of this district also correlates clearly with that farther west. These drifts both fall in the last quarter of the Pleistocene glacial epoch, and so are much better preserved than the Jerseyan drift, which seems likely to fall in the first half of the glacial epoch.

The present study, covering three field seasons, naturally divides itself into three parts dealing with (a) the Susquehanna Valley; (b) the Delaware Valley and the drift area in New Jersey; (c) northwestern Pennsylvania. These will be taken up in the order named.

DRIFT IN THE SUSQUEHANNA DRAINAGE BASIN

REVISION OF LEWIS AND WRIGHT'S MAPPING OF THE MORAINE.

The present writer's studies have shown that there was a more definite adjustment of the border of the ice sheet to the topography than is shown by the Lewis and Wright map, there being protrusion into the broad deep valleys and reentrants at the prominent ridges. The line as drawn by Lewis and Wright often includes between the ends of valley lobes high tracts which do not appear to have been covered by this ice sheet. These were generally covered by ice in an earlier glacial stage and thus carry glacial deposits, so it is not surprising that these earlier students included such deposits with the deposits of Wisconsin age.

At the eastern border of the Susquehanna drainage basin the Wisconsin ice sheet overrode Nescopeck Mountain about as far west as the crossing made by the electric railway from Wilkes-Barre to Hazleton at an altitude of 1,700 feet. It extended down Nescopeck Valley to St. Johns where it is only 1,000 feet, and into Lehigh Valley about to the line of Luzerne and Carbon counties below White Haven with an altitude of about 1,300 feet or 200 feet above the river. Between these protrusions the border follows the north slope of Yeager Mountain, reaching to 1,500 or 1,600 feet above sea level. Till deposits south of that mountain on both slopes of Green Mountain near Zehner, which were included in the terminal moraine by Lewis and Wright, in the present writer's opinion are to be referred to the Illinoian stage of glaciation. The till is more deeply weathered than that of the moraine. It is also of very different texture, being clayey with only a moderate number of stones imbedded, whereas the Wisconsin drift is looser textured and full of stones of all sizes.

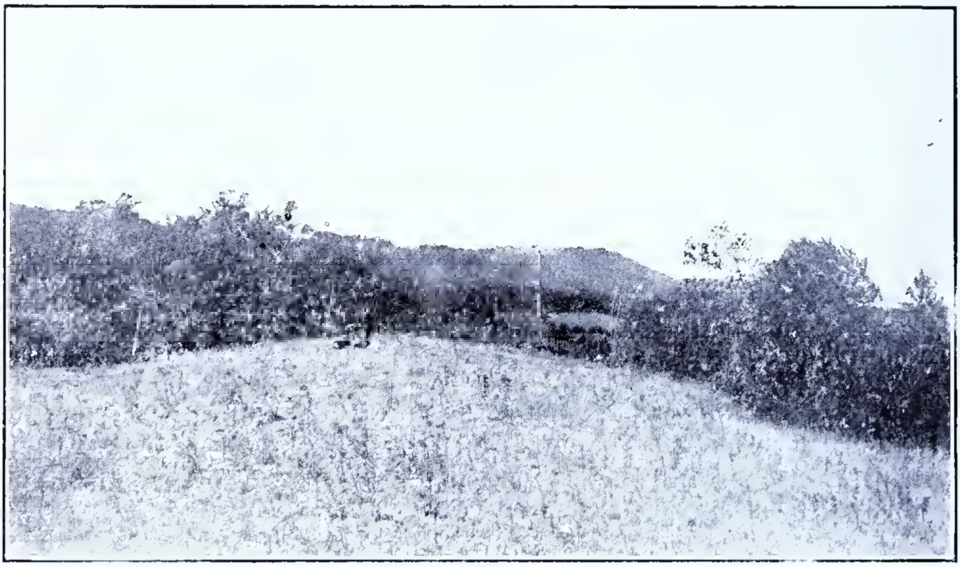


Figure 2. Cobble ridge, shaped by wave action from lateral moraine. East of Nescopeck, opposite Beach Haven. Photo by H. L. Fairchild.

In the valley of North Branch of Susquehanna River the moraine crosses between Berwick and Beach Haven. Its topography and structure are shown in Figure 1. Its border descends from about 1,700 feet on the crest of Nescopeck Mountain to 600 feet at the river. It rises to 1,300 feet on the crest of Lee Mountain only 4 miles north from the river, and covers points on Huntington Mountain, 2 miles farther north, that are 1,500 feet above sea level. It was suggested by Lewis and also by White that the ice border followed the south base of Lee Mountain for several miles west from Berwick and deposited the till which is conspicuous in that district. It was assumed that the ice overrode the mountain and faced toward the Susquehanna Valley. In the present writer's opinion this till is Illinoian and was laid down by an ice lobe occupying the river valley and having its borders against Lee Mountain on the north and Nescopeck Mountain on the south. (Fig. 1 and 12.) The till, like that south of Nescopeck Mountain, is more deeply weathered and more clayey than in the Wisconsin terminal moraine.

The border of the Wisconsin drift is traceable down the north slope of Huntington Mountain past Jonestown to Huntington Creek with a descent of 800 feet in 7 or 8 miles, its altitude at the creek being 700 feet above sea level. But the ice covered hills over 1,000 feet above sea level within a mile north of the creek. Fishing Creek Valley is along the border from Benton down to Zaner. Near Benton the border crosses to the west side of the valley at an altitude of about 800 feet, but the hills directly east of Benton carry Wisconsin drift deposits at over 1,100 feet.

The border is mapped westward from northern Columbia County by Lewis and Wright along the south base of North Mountain, it being assumed that the ice passed over the mountain and terminated at its southern base. In the present writer's opinion the part of North Mountain west of the Nordmont-Wilkes-Barre road stood some hundreds of feet above the limits of the Wisconsin ice sheet, so the border is likely to cross this mountain some miles farther east than this highway, and then follow the north base of North Mountain westward to the west end of the mountain, its axis of movement being along Muncy Creek Valley. The limits of Wisconsin drift on this north base seem to be about 1,700 feet on the meridian of Nordmont and 1,500 feet opposite Sonestown. West of North Mountain ice tongues extended south from Muncy Creek Valley into Beaver Run and Big Run, tributaries of Little Muncy Creek, and into Greggs Run, an eastern tributary entering Muncy Creek at Hughesville. The limits of the ice are marked by morainic knolls in each of these valleys. Those on Beaver Run are near the mouth of the stream at an altitude of 800 to 900 feet. Those on Big Run end at about 900 feet two miles above its mouth. On Gregg Run the moraine comes down to 700 feet and is well developed between 700 and 800 feet above sea level 3 to 4 miles from the mouth. On Muncy Creek the terminus of morainic features is just below Tivoli at about 700 feet. In each of these valleys there were ice tongues 2 to 3 miles long. The Wisconsin ice appears to have followed the west base of North Mountain to the hamlet of North Mountain and have had its limit there at about 1,300 feet. In the district farther east on the south side of North Mountain there is a red clayey till that seems referable to the Illinoian stage of glaciation. This is conspicuous near Lungerville and also southward past Unityville. It may have been brought in by a southwestward movement along the south side of North Mountain. On the divide between the Muncy Creek and Loyalsock Creek drainage the border of the Wisconsin ice was near the western line of Sullivan County where prominent ridges reach an altitude of over 2,100 feet. From there the border passed westward to Bear Creek and crossed that valley at about 1,400 feet. It then followed down the south side of Bear Creek to Loyalsock Creek near Barbours. A tongue of ice extended down Loyalsock Creek nearly to the mouth of Wallis Run, with Cove Mountain on its north side. The border passed around the east and north sides of Cove Mountain and made a protrusion down Wallis Run nearly to its mouth. From Wallis Run northwestward into New York no attempt was made to revise the mapping of Lewis and Wright. The border is in a forested region with few roads and detailed mapping is very difficult. The present writer visited the place where the border crosses Pine Creek a little below Lloyd P. O. (Blackwell Station) and found the limit to be as placed by Lewis. See page 62 for change of border near Wallis Run.

The topographic maps of the Laporte, Eaglesmere, and Warrensville quadrangles have been issued since the writer completed his field work in the district covered by them. The topography shown on these maps suggests the need for slight shifting of the borders of the Wisconsin and Illinoian drifts from their position as given on Plate 1. The Warrensville map shows a large area north of Wallis Run less than 1500 feet in altitude. This serves to explain the pronounced westward extension of the Wisconsin drift border in that locality. It is probable that a considerable part of the tract lying between Wallis Run and Loyalsock Creek was not covered by the Wisconsin icesheet. Whether it was covered by the Illinoian icesheet is not determined.

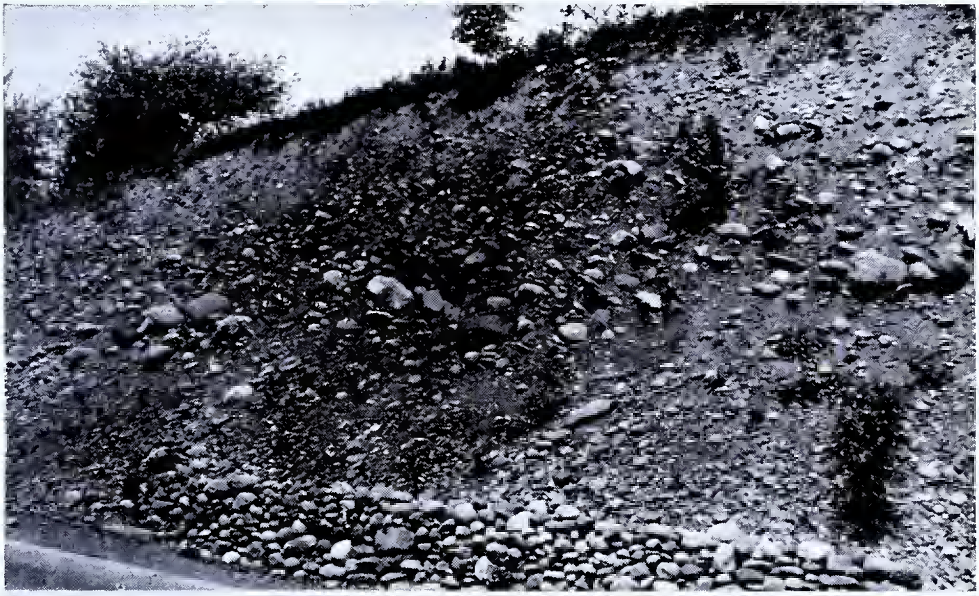
In the Laporte quadrangle the presence of small knolls with swampy tracts on their borders, which seem to be features of the Wisconsin drift, above and outside the limits that had been given that drift on Plate 1, suggest a need for a slight revision of that drift border on North Mountain. The Illinoian icesheet may also have had somewhat greater extent on North Mountain than shown in Plate 1.

WISCONSIN GRAVEL TRAINS ON THE SUSQUEHANNA AND TRIBUTARIES

General statement. The writer examined the valley trains of Wisconsin gravel on the North Branch of the Susquehanna and its tributaries, and of the West Branch and its tributaries so far as they lie outside the Wisconsin drift border. The height reached by the waters issuing from the Wisconsin ice sheet is clearly shown on all these valleys by moderately eroded terraces carrying gravel of relatively fresh appearance. These terraces stand much lower than the terrace that carries the Illinoian gravel, and have suffered markedly less erosion. It was found, however, that it is a much easier matter to determine the full height to which the Wisconsin floods reached in the part of the Susquehanna valley inside the limits of the older drift than in the part outside, for in the part inside there is scarcely any terracing at higher levels than were reached by the Wisconsin floods. In the part outside, as far down as the head of the gorge at Creswell, 3 miles below Washingtonboro, Lancaster County, terraces are much more conspicuous at all levels from that of the Illinoian filling down to the present flood plain. There may be room for some difference of opinion as to what should be regarded as the Wisconsin limit in this part. It is also a difficult matter to fix upon a limit for the Wisconsin drainage inside the Susquehanna gorge.

NORTH BRANCH OF SUSQUEHANNA RIVER

The Wisconsin gravel train is well defined on the North Branch of Susquehanna River from the border of the moraine, east of Berwick, down to the junction of this stream with the West Branch, at Northumberland. Except for a short distance near the head of the gravel plain, where it is about 120 feet above the river, the surface of this gravel train is generally between 40 and 60 feet above the river. The head of the gravel plain is above 600 feet, while the river there is 480 feet above sea level. The deposit is of very coarse material with bowlders and large cobblestones for a mile or more from its head, but the surface is plane, and the stones of all sizes show much water wear (Fig. 3). The slope is rapid as far down as Mifflinville, about 6 miles, with a descent of 60 feet in that distance. The river falls only about 6 feet in this interval. Between Mifflinville and Bloomsburg the plain falls about 20 feet in 8 miles, but it falls 20 feet in the next 4 miles to Catawissa, and reaches a level 100 feet lower than at the head of the gravel train. The river makes a fall of only 20 feet in the same interval. It falls 20 feet more in the next 15 miles, and the gravel plain makes the same descent. In this part of the valley a



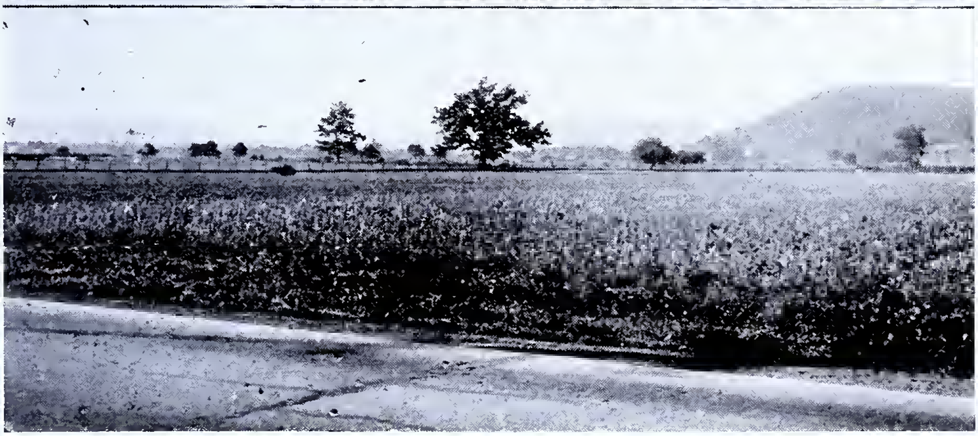


Figure 3. Roadside section of Wisconsin gravel plain just east of Berwick.

Figure 4. Outwash gravel plain near Montoursville at 540 feet A. T.

very bouldery deposit of Illinoian drift has been cut into by the post-Illinoian drainage. A terrace opposite Danville, on the south side of the river, and below Chulasky, on the north side, stands below the 500-foot level, while a morainic or hummocky surface sets in just above that level. The terrace is about as thickly strewn with bowlders as the hummocky tract, which may indicate that the boulders came from a part of the hummocky tract that had been covered and smoothed by the stream. The upper limit of stream action in this part of the valley is thus clearly within 40 or 50 feet of the present low water level of the river. This slight deepening apparently is all that has taken place here since the Illinoian ice disappeared. This terrace may have been covered by the Wisconsin flood stage even if it had been developed in pre-Wisconsin time. It is about 6 miles from the place where the river is 440 feet above sea level down to the junction with the West Branch, and 5 miles farther the river is 420 feet above sea level. At that place the highest terrace is about 460 feet above sea level, there being a hummocky drift surface at 480 feet. Thus the post-Illinoian deepening there is less than 60 feet. But in Sunbury, only 4 miles above this place, a terrace of Illinoian gravel is 505 feet and is thus about 80 feet above the river.

Fishing Creek. This northern tributary of the North Branch of Susquehanna River crosses the outer moraine of Wisconsin drift near Benton. (Fig. 5.) A gravel train heads in it just above the village at an altitude of 780 feet. The gravel is a conspicuous deposit all along the valley below there, so it is difficult to understand what led Lewis[1] to make the following statement:

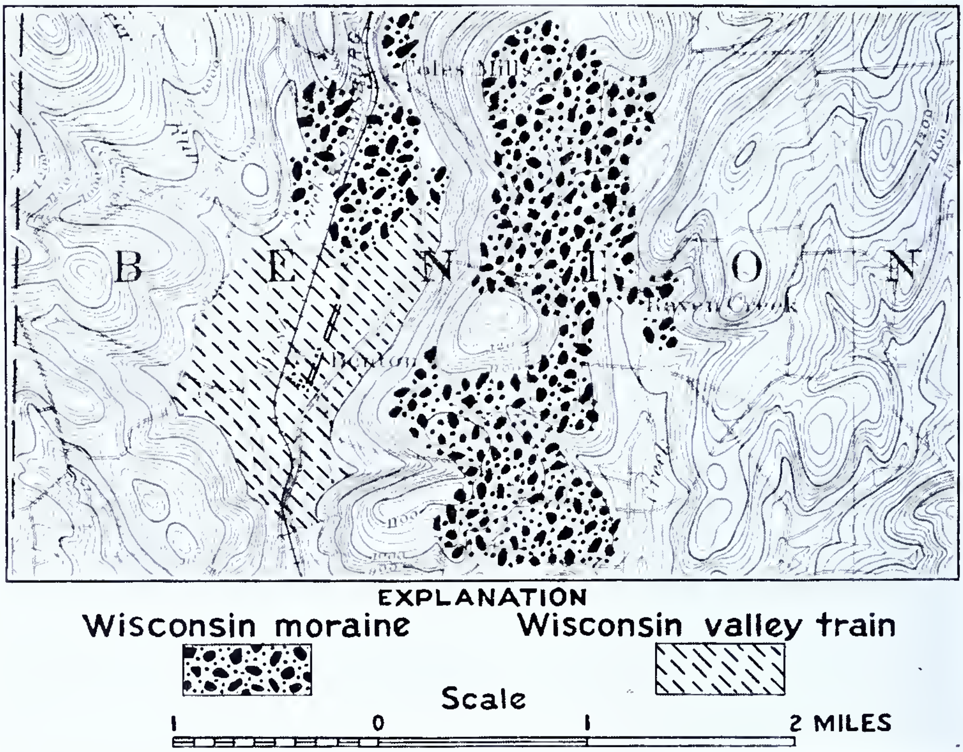


Figure 5. Topographic map of part of Bloomsburg quadrangle showing Wisconsin terminal moraine near Benton, and gravel train on Fishing Creek.

> It is a curious fact, that although the moraine from Asbury to this point runs so near Fishing Creek, no drift whatever, stratified or unstratified, occurs in the valley of that creek. The slates and shales of VIII are exposed on both banks of the creek; and the sandy alluvium forming the fertile bottom land is perfectly local. The edge of the glacier must have been drained backwards.

The valley train was built up to a level only 30 to 40 feet above the creek where it connects with the moraine, but it shows a transition from plane to morainic surface characteristic of the moraine-headed terrace. It also is composed of well rounded stones of various kinds of rock many of which are not local. Eight miles below Benton, at the mouth of Huntington Creek, a tributary glacial gravel train comes in from the moraine 2 miles up its valley. In this gravel train there are boulders as well as smaller stones of various kinds of rock. From the junction of the two valley trains clear to the mouth of the valley the train is medium to coarse gravel which shows a gradual decrease in size down stream. From the contours on the map of the Bloomsburg quadrangle it appears that there is a fall of 60 feet in 4 miles from Benton to Stillwater, and 100 feet more in the next 4 miles to the mouth of Huntington Creek. Another 100-foot fall is made in 14 miles to the mouth of the creek. The general level of the terrace of glacial gravel is less than 40 feet above the creek all along its course to the Susquehanna valley.

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[1] Pennsylvania Second Geol. Survey, Rept. Z, p. 120, 1884.

Nescopeck Creek. This southern tributary of the North Branch of Susquehanna River leaves the outer moraine of Wisconsin drift at St. Johns at an altitude of 1,000 feet above sea level, and comes into the river opposite Berwick at 480 feet. The level of the Wisconsin filling there, as indicated above, is nearly 600 feet, thus giving a fall of 400 feet to the Wisconsin plane of filling. There is a low bouldery terrace about 20 feet above the stream where it leaves the moraine. But very little glacial gravel seems to have been carried down the creek, so it does not appear to have a definite Wisconsin terrace. It is probable that only a small amount of ice passed over Nescopeck Mountain into the basin drained by Nescopeck Creek, and this may account for the absence of a definite valley train of glacial gravel.

WEST BRANCH AND TRIBUTARIES

The Wisconsin ice sheet did not extend to the West Branch of Susquehanna River, but it came within about 15 miles of the river on two of its tributaries, Muncy Creek and Loyalsock Creek. It also covered the headwaters of two other tributaries, Lycoming and Pine creeks. Both of these tributaries have conspicuous deposits of glacial gravel leading from the Wisconsin terminal moraine down to the Susquehanna Valley.

The gravel plain on Pine Creek is about 580 feet above sea level where it opens into Susquehanna Valley west of Jersey Shore. This is 60 feet above the level of the river. The material is very coarse here, with a large percentage of cobblestones, a condition that prevails all the way up to the moraine.

The Wisconsin ice sheet covered the valley of Lycoming Creek as far down as Bodine. Between Bodine and Ralston a low plain scarcely 20 feet above the creek occupies nearly the full width of the valley. This gives place near Bodine to a bouldery terrace about 60 feet above the stream, which forms the head of the glacial drainage at the culminating position of the ice front. It is a more conspicuous feature than the moraine, which is represented by scattered knolls along the border of the valley above this point. This terrace is about 760 feet above sea level at Fields Station. It falls to 700 feet at Trout Run 4 miles below, and to 600 feet at Cogan Valley 6 miles farther down. Six miles below Cogan Valley it reaches the border of the Susquehanna Valley, and there stands about 560 feet above sea level. It contains bowlders up to 2 feet or more in diameter as far down as the mouth of Grays Run, about 3 miles from its head, and well rounded stones up to one foot in diameter as far down as Trout Run, while cobbly material extends clear to the mouth. Below Grays Run the altitude of the terrace is generally less than 40 feet above the stream. It continues down the Susquehanna about 40 feet above the river. Below Bottle Run, opposite Wildwood Cemetery, Williamsport, deposits of Illinoian drift are present on the west side of the valley of Lycoming Creek. A narrow clayey terrace a few feet above the gravel train has been formed on the edge of this drift deposit. Its elevation is less than 580 feet. This may antedate the Wisconsin stage, as an incident of erosion following the disappearance of the Illinoian ice. Perhaps it was covered in flood seasons in the Wisconsin stage.

On Loyalsock Creek morainic topography extends down to within a mile of the mouth of Wallis Run, or about 10 miles from the mouth of the creek. A terrace there sets in at a level 50 to 60 feet above the creek, and a similar terrace occupies the lower end of Wallis Run. The ice border seems also to have been along the slope of the south bluff of Loyalsock Creek as far up as the mouth of Big Bear Creek at Barbours, with a slight protrusion into the lower end of Little Bear Creek Valley. See note on page 62 for correction.

The deposits in this gravel train are thickly set with bowlders as far down as Loyalsock village, about 3 miles from the head of the terrace, and this part was included by Lewis in the moraine. Well rounded stones up to one foot in diameter are present in the gravel train clear down to Montoursville, where Loyalsock Creek enters the Susquehanna River. The altitude of the head of the gravel train is estimated to be about 650 feet above sea level. At Montoursville it is 540 feet. There thus appears to be a fall of 110 feet in 10 miles or 11 feet per mile. It is probable that some of the large stones found in this gravel train between Loyalsock and Montoursville were derived from the Illinoian drift which is present in that part of the valley, though some of them may have been derived from the Wisconsin drift border. Illinoian bowlders are conspicuous in places on the valley slopes above the level of the surface of the Wisconsin valley train, and the Illinoian drift extends down to the level of the Wisconsin terrace.

On Muncy Creek morainic topography is present as far down as Tivoli, about 15 miles from the mouth of the creek. The valley is narrow for two miles below Tivoli. It then widens and contains a conspicuous deposit of Wisconsin gravel. The level surface of this deposit is only about 40 feet above the stream where fully preserved, and there are terraces in it at 20 to 30 feet. The material is not so coarse as in the valley train on Loyalsock Creek, much of it being of a grade suitable for highway use. East of Muncy 1½ miles the gravel train has an elevation of 540 feet. This is about 2½ miles in direct line from the Susquehanna River, and about 20 feet above the level of the gravel train on the river at the mouth of the creek, at Muncy. As the gravel train is 680 feet above sea level at its head below Tivoli, there is thus a fall of 160 feet in about 15 miles to the Susquehanna Valley. Gregg Run, a tributary of Muncy Creek, has a gravel train heading in the Wisconsin moraine 4 miles above Hughesville at 700 feet above sea level. It falls to 600 feet at Hughesville, or 25 feet per mile.

From the data given above it appears that the gravel train in the Susquehanna valley has a fall of about 20 feet between each of the affluents that brought in Wisconsin gravel, its elevation at the mouths being 580 feet at Pine Creek, 560 feet at Lycoming Creek, 540 feet at Loyalsock Creek, and 520 feet at Muncy Creek. Continuing down the valley from Muncy the valley train drops below 500 feet 1½ miles below Montgomery, opposite the place where the river drops below 460 feet, as shown by the Milton topographic map. The valley train is below 480 feet midway between Watsontown and Milton, and the river there is below 440 feet. A similar relation exists 2 miles above Selinsgrove, where the gravel train drops below 460 feet, and the river below 420 feet. This brings the description to the place where that of the train on the North Branch of the Susquehanna was carried. The material in the valley train along the West Branch is rather coarse as far down as the mouth of Loyalsock Creek, but is finer below there, and in places is somewhat sandy. It includes also a considerable quantity of local rock material, some of which is but little rounded, because of the short distance it has traveled.

There are two tributaries of Little Muncy Creek on which gravel trains head in the Wisconsin moraine. One on Beaver Run heads at about 820 feet, and one on Big Run at about 900 feet above sea level. These come together at Lairdsville at about 750 feet above sea level, about two miles from their heads.

SUSQUEHANNA RIVER BELOW SUNBURY

Through the mountains between Sunbury and Harrisburg the valley has terraces only in the lowlands between the ridges. These terraces are at various levels below the Illinoian terrace, but the best defined terrace is generally about 40 feet above the river, with a few places about 60 feet, or at a similar altitude above the stream that the Wisconsin gravel train maintains on the West Branch and lower part of the North Branch. This fact and the rather fresh appearance of the material on the terrace seem to justify reference of this terrace to the Wisconsin glacial stage.

The terrace at the mouth of Middle Creek, 1½ miles below Selinsgrove, is just over 440 feet above sea level. The terrace at the mouth of Mahanoy Creek above Herndon barely reaches 430 feet in its back part, but has a broad development below that level. The river here has an elevation of 403 feet. At the two Mahantango Creeks, and also at Liverpool the Wisconsin filling is a little above the 420-foot level at the back side next to the bluffs. The river drops below 380 feet above Liverpool. A gravel deposit south of the village of Millersburg is slightly below 420 feet, and nearly 50 feet above the river. At McClellan, 3 miles below Millersburg, the best-defined terrace is above the 420-foot level. This is more than 50 feet above the river. The stream drops below the 360-foot level above Half Falls, about 2 miles below McClellan. About 5 miles farther down, the river passes below 340 feet. At Haldeman Island whose highest points are 411 feet the Wisconsin outwash is found on two terraces, the higher of which lies at an elevation of 370 feet which is 30 feet above the river. At New Buffalo, a mile above this island, a terrace with fresh gravel is just below 380 feet above sea level, and more than 30 feet above the river.

At Duncannon, just below the mouth of Juniata River, a terrace between 360 and 370 feet seems likely to mark the limit of the Wisconsin valley train. The river there is 332 feet above the sea level. At the cove below Duncannon the terrace is well defined at about the 360 foot level.

After passing through the two mountain ridges below Dauphin the river has an abandoned channel, followed from there to Harrisburg by the Pennsylvania Railroad. Between it and the river is a strip of sandy and gravelly land extending south to the Capitol grounds. The Wisconsin drainage does not seem to have completely covered this strip, but may have reached about to the 345-foot level, as the gravel is of relatively fresh appearance up to that height, which is 40 feet above the river. But the Capitol grounds stand above 360 feet, and the gravel there above 350 feet is deeply weathered as in the Illinoian terrace along the east side of the valley in Harrisburg. It is probable that the limit of Wisconsin waters was below rather than above 350 feet in this city.

Just below New Cumberland there is an abandoned channel on the west side of the river, drained in part by Marsh Run. It is below 330 feet, but a terrace at about 335 feet borders it, and carries a loamy deposit of fresher aspect than the gravel (Illinoian) on high land between it and the river. This deposit seems likely to be at least as young as the Wisconsin glacial stage, and puts the river action as high as 335 feet there at that time. Terraces between 320 and 340 feet above sea level are preserved along the valley as far down as Bainbridge which seem likely to have been covered by the Wisconsin drainage. The river drops below 260 feet about three miles above Bainbridge, so the terrace near this village is about 60 feet above the stream. Between Bainbridge and Marietta a terrace that seems referable to the Wisconsin stage stands between 280 and 300 feet. The terrace drops below 280 feet at Marietta. It is exceptionally broad and flat for about three miles above Marietta, as may be seen by reference to Figure 6, a part of the topographic map of the Middletown quadrangle, as well as the photo Figure 7. It stands about 60 feet below the Illinoian valley

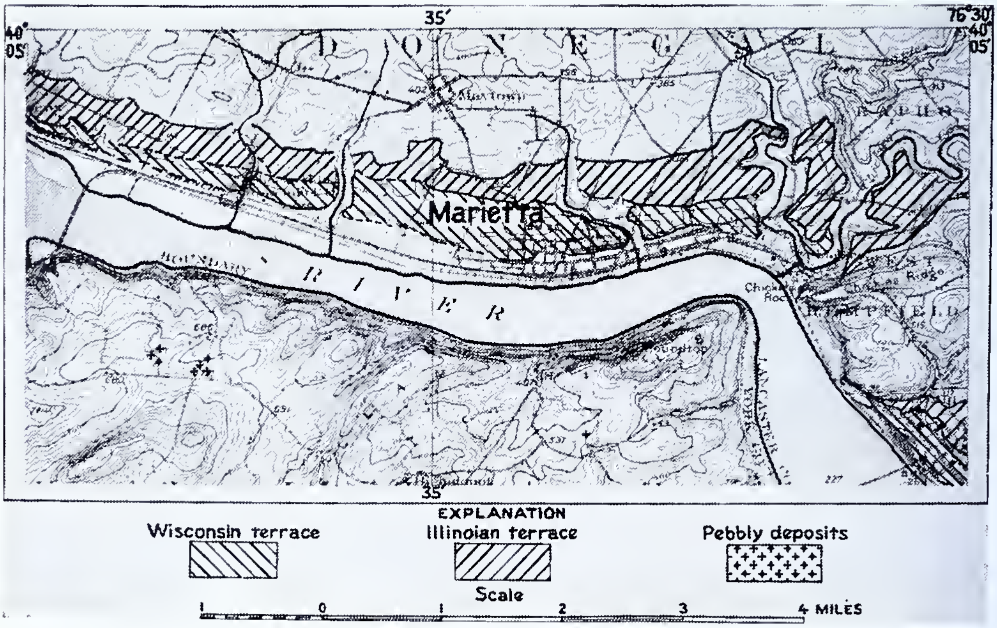

Figure 6. Topographic map of part of Middletown quadrangle showing Illinoian and Wisconsin terraces near Marietta.

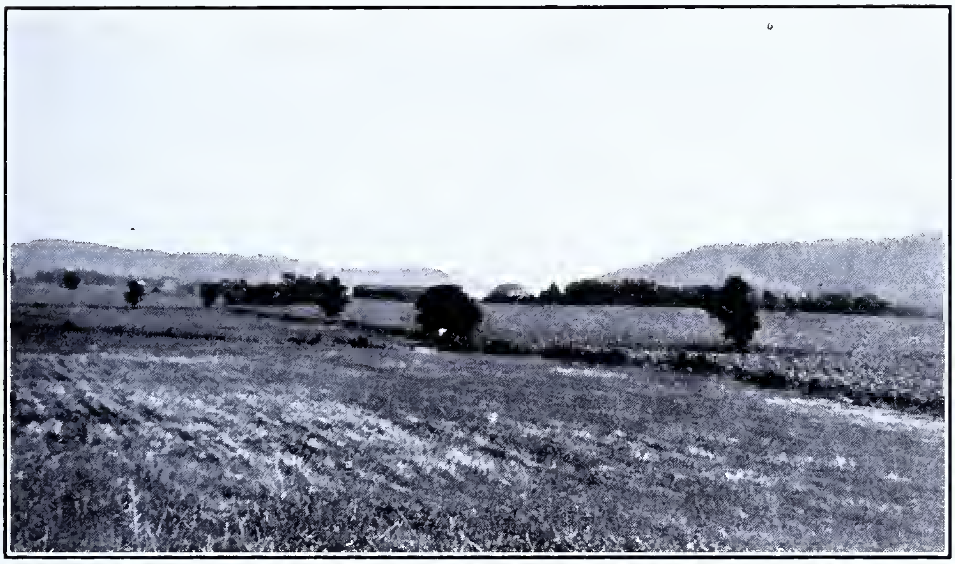

Figure 7. Wisconsin terrace near Marietta. Photo by Geo. H. Ashley.

train, and is 50 feet above the river. The erosion and breaking down of its surface is markedly less than in the Illinoian terrace, and seems in keeping with a terrace of Wisconsin age. There is some terracing of the slope between it and the river in the vicinity of Marietta. In fact the terracing displayed near Marietta is more conspicuous than at any other place noted along the river.

The Wisconsin terrace is not so definitely preserved below Marietta, and there is some uncertainty as to the level at which the river stood at that stage. Terracing below Washingtonboro at about 270 feet, or 50 feet above the river, seems likely to be referable to the Wisconsin stage. A narrow terrace about 40 feet above the river from Washingtonboro down to the head of the gorge at Creswell may mark the level of the river at that time. Its altitude is about 240 feet above sea level at the head of the gorge.

The writer found no features within the gorge that can be clearly referred to the work of the river at the Wisconsin stage. The Talbot formation of the Coastal Plain series stands about 40 feet above sea level at the mouth of the Susquehanna, and this seems to be the equivalent of the Cape May formation on the Delaware, which has been referred to the Wisconsin stage by the geologists of the New Jersey Geological Survey. If this correlation is correct, the Talbot would be the equivalent of the terrace under discussion on the Susquehanna River. The fact that it stands at the same height above present drainage also seems significant. The Susquehanna probably has deepened the gorge about 40 feet since the Wisconsin stage.

ILLINOIAN DRIFT IN THE SUSQUEHANNA DRAINAGE BASIN.

Complexity of the pre-Wisconsin drift. From the outline of the results of earlier studies given above it will be seen that the extra-morainic drift outside the Wisconsin terminal moraine mapped by Lewis and Wright had come to be recognized as a glacial deposit rather than a flooded river deposit by the time Wright and Williams had completed their investigations. But it was referred by them to a time only a little earlier than the time of deposition of the Wisconsin terminal moraine. Even where the name Kansan was applied by Williams to the extramorainic drift it was made clear that he did not put the Kansan far back of the Wisconsin stage, but regarded it as a first phase of the same glaciation. There seems to have been no clear recognition of the presence of extramorainic drifts of widely different age in the eastern Pennsylvania district until the present writer's studies in 1926 brought out evidence of such difference. A part of the drift now seems to correspond in age to the Illinoian or third drift of the North American series, while a part seems old enough to correlate with either the first or second drift of this series. The older drift as exposed in New Jersey has been termed the Jerseyan drift, and the same drift seems to be present in eastern Pennsylvania. Nearly all the drift noted by I. C. White seems referable to the Illinoian stage, but drift noted by E. H. Williams and assistants appears to be partly of pre-Illinoian age. It is significant, however, that the drift near Bethlehem, Pa., where Williams did his most intensive work, is of Illinoian age. It is not surprising, therefore, that he interpreted it as merely an early phase of the Wisconsin glaciation.

The Illinoian drift of the Susquehanna drainage basin is found chiefly in the lowlands between the mountain ridges, and seems to have been deposited by lobes or tongues of ice that invaded these lowlands without completely covering intervening ridges. Some of the reentrants between these lobes appear to extend back inside the limits of the Wisconsin drift. Their exposed parts are thus best treated as independent areas, and the discussion will begin with the one along the North Branch of Susquehanna River.

ILLINOIAN DRIFT BORDERING NORTH BRANCH OF SUSQUEHANNA RIVER

Distribution. A conspicuous Illinoian ice lobe projected down the valley of North Branch of Susquehanna River from the border of the Wisconsin drift just above Berwick to its junction with West Branch of Susquehanna River at Northumberland. A sublobe there branched off and extended about four miles up West Branch valley, to Winfield. The main lobe continued down the Susquehanna valley to Selinsgrove, and terminated in a low area west of that village. (Fig. 8, and Pl. I). The length of the lobe as exposed outside the Wisconsin drift border is about 40 miles. Its greatest width is not more than 8 miles. For a few miles west from Berwick it was confined between Nescopeck Mountain on the south and Lee Mountain on the north (Figure 12). It filled lowlands along and near the Susquehanna farther west and probably covered intervening uplands. But its deposits are very scanty on the uplands, and on parts of the lowlands, so that the limits of the lobe are hard to define. A few places appear to have been exceptionally favorable for the lodgment of drift, but in general the deposits are very light, and in places the ice appears to have eroded or sculptured the rock surface and left scarcely a trace of drift on it. The deposits are exceptionally heavy in the headwaters of Little Roaring Creek near the highway from Danville to Elysburg 3 to 4 miles south of Susquehanna River, and up to an altitude 500 feet above the river. The occurrence at this altitude seems to necessitate the overriding of

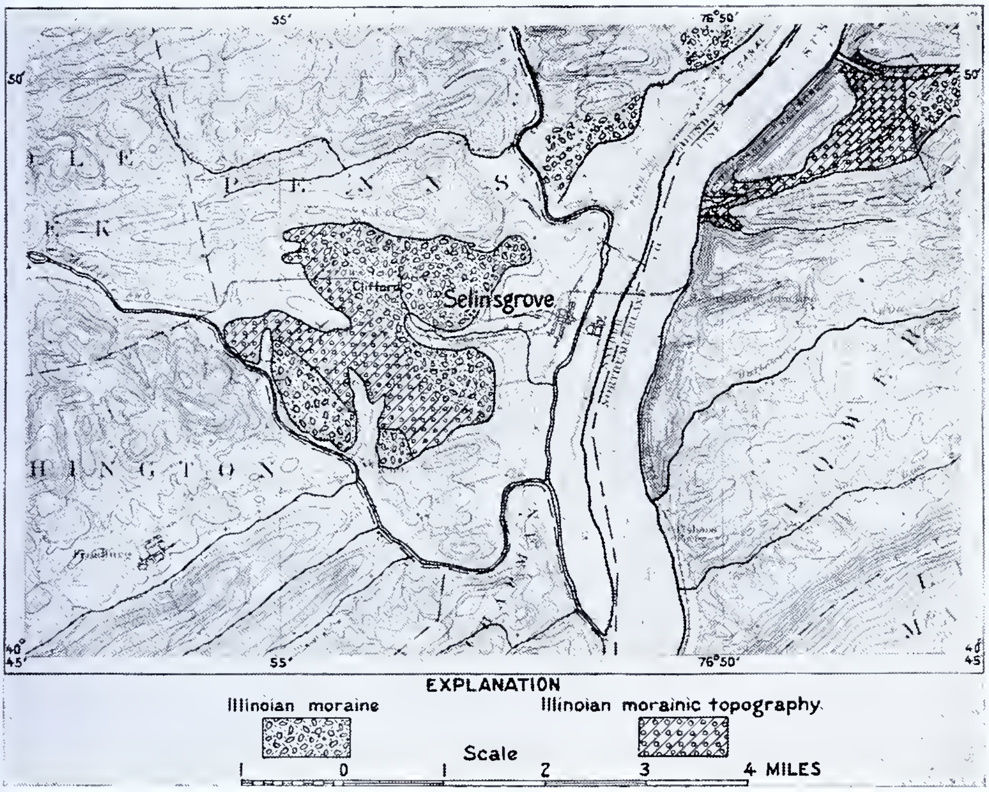

Figure 8. Topographic map of part of Sunbury quadrangle showing Illinoian drift at Selinsgrove.

lower tracts nearer the river on which the drift deposits are scanty. Below Danville the ice lobe appears to have been much narrower than above that city, and to have had a general width of only about 2 miles, yet it extended 20 miles farther down the valley. At its terminus the lobe covered ground more than 200 feet above the river. But the drift is present on slopes down to within 60 feet of the present river level. There has thus been only a very moderate deepening of the Susquehanna valley since the deposition of the drift.

An instance of oversteepening by glacial erosion may be found in the precipitous bluff opposite Northumberland shown in Figure 9, which stands west of the junction of West Branch and North Branch valleys where the ice lobe appears to have split. It rises almost perpendicularly to a height of 400 feet above the river, and that too on an inner curve of the stream where deposition rather than cutting should have taken place.

Character of the drift. The Illinoian drift in this lobe is generally of clayey material, with only occasional pockets and beds of sand and gravel. The color is usually reddish, probably mainly because of high oxidation, as there is only a small amount of red rock material in the drift here. The color is decidedly in contrast with the yellowish brown color of the oxidized portion of the Wisconsin drift in neighboring localities.

Topography of the drift. In a few places the Illinoian drift has a hummocky morainic topography, but generally the surface is nearly

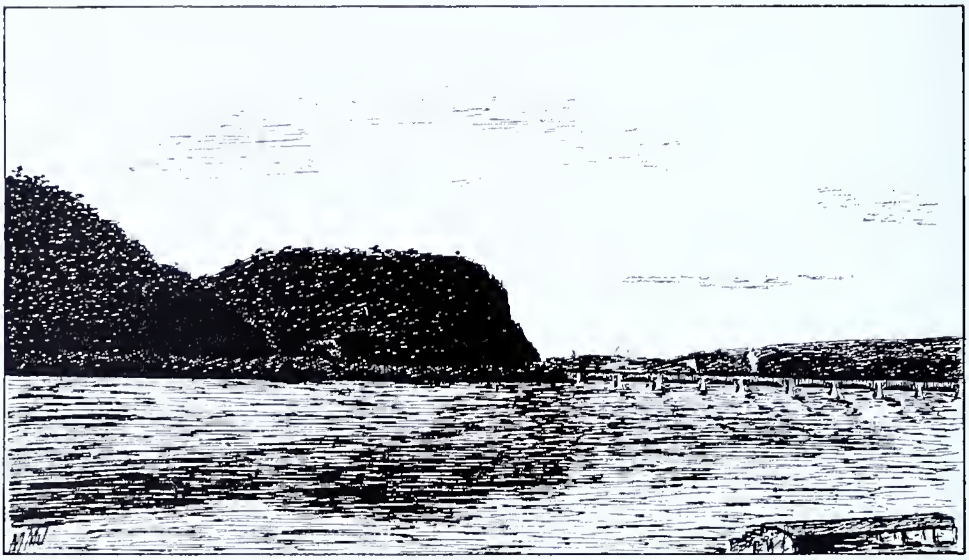

Figure 9. Bluff showing oversteepening, perhaps as a result of glacial action. West side of Susquehanna River at junction of West Branch and North Branch.

plane. The most conspicuous display of morainic topography is at the terminus of the lobe, west of Selinsgrove (Figure 10). An area there of three or four square miles has many small knolls 10 feet or less in height among which are saucer-like depressions 3 to 5 feet in depth. The Pennsylvania Railroad makes cuts in some of these knolls near Clifford Station to a depth of about 8 feet, or to the level of their base. The drift here carries only small boulders, usually less than a foot in diameter. The limestone pebbles seem to have been completely dissolved as far down as the cuts extend, and many of the crystalline pebbles are in an advanced state of decay. In this respect the Illinoian drift is more strikingly in contrast with the Wisconsin drift than in its topography.

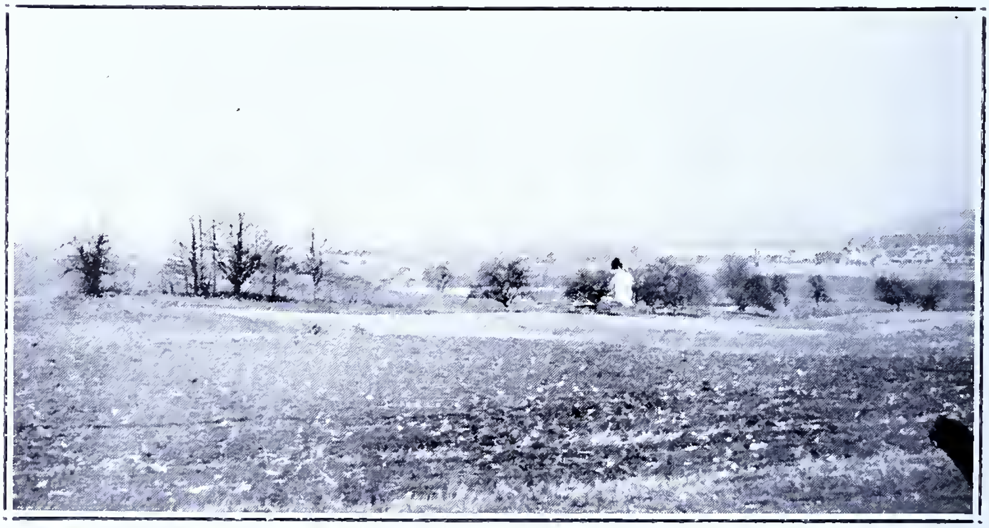

Figure 10. Morainal topography 2½ miles west of Selinsgrove shown in foreground. Photo by Geo. H. Ashley.

Morainic topography is also displayed in a recess on the east side of the Susquehanna about 3 miles below Sunbury, and up to an altitude about 200 feet above the river. This deposit seems likely to have been brought in by a lateral movement of the ice eastward from the river valley rather than by southwestward movement across a low pass between Little Shamokin Creek and this recess.

The Illinoian drift has a mild type of swell and sag topography in a lowland back of the river bluffs north of the North Branch of Susquehanna River 3 to 5 miles above Northumberland near the borders of the Sunbury and Shamokin quadrangles, and wells at farm houses show the drift here to be over 35 feet thick. The altitude here is 600 to 640 feet. Scattered boulders and cobblestones and patches of drift are present at higher altitudes west from here on the south slope of Montour Mountain, but they may pertain to a pre-Illinoian stage of glaciation.

A mild type of morainic topography is displayed in the drift deposits in the headwaters of Little Roaring Creek south of Union Corner at an altitude about 1000 feet above sea level (Figure 11). The drift here seems to have considerable thickness, and also along the Danville-Elysburg highway north from Union Corner clear to the Susquehanna valley at all altitudes between 1000 and 600 feet. A strip lying between Little Roaring Creek and Logan Run has a markedly greater amount of drift than is found either to the east or west of these streams. Possibly the Illinoian ice had a lateral protrusion into this district, induced perhaps by the obstruction offered by Blue Hill, south of Danville and Montour Ridge north of that city, to the westward course down the Susquehanna valley. But the main flow of ice continued down the valley past Danville.

A thick deposit of Illinoian drift with somewhat knolly surface is present 2 miles northwest of Bloomsburg, in a low strip extending west from Fishing Creek valley from near the mouth of Little Fishing Creek past Buckhorn village. The thick deposits are below the 700-foot level, their surface being mainly between 600 and 660 feet.

In the lowland followed by the Reading Railroad eastward from Danville there is considerable drift, but there are only a few places where it has a knolly surface, chiefly at the east end near Rupert.

From Fishing Creek at Orangeville, eastward to the border of the Wisconsin drift north of Berwick there is a strip of thick drift along the base of Knob and Lee mountains between one and two miles in width, several wells having penetrated it 50 to 60 feet before entering rock. Its surface, which rises eastward to between 1000 and 1100 feet above sea level (Figure 12) is somewhat undulating, but not characterized by definite knolls or hummocks of morainic type. A chain of rock knobs lies south of it from Berwick Heights westward. These may have stood above the Illinoian ice sheet. Several of them are very steep on the south slopes, a feature that may be due to erosion by the lobe of ice that occupied the Susquehanna valley. The strip of drift north of these knobs is thickly strewn with boulders, many of which were derived from the formations in the mountain along its north border. These boulders and the thick deposits of till drew the attention of White and of Lewis, as already indicated, and led White to suggest the possibility of an extension of the ice sheet over this district.

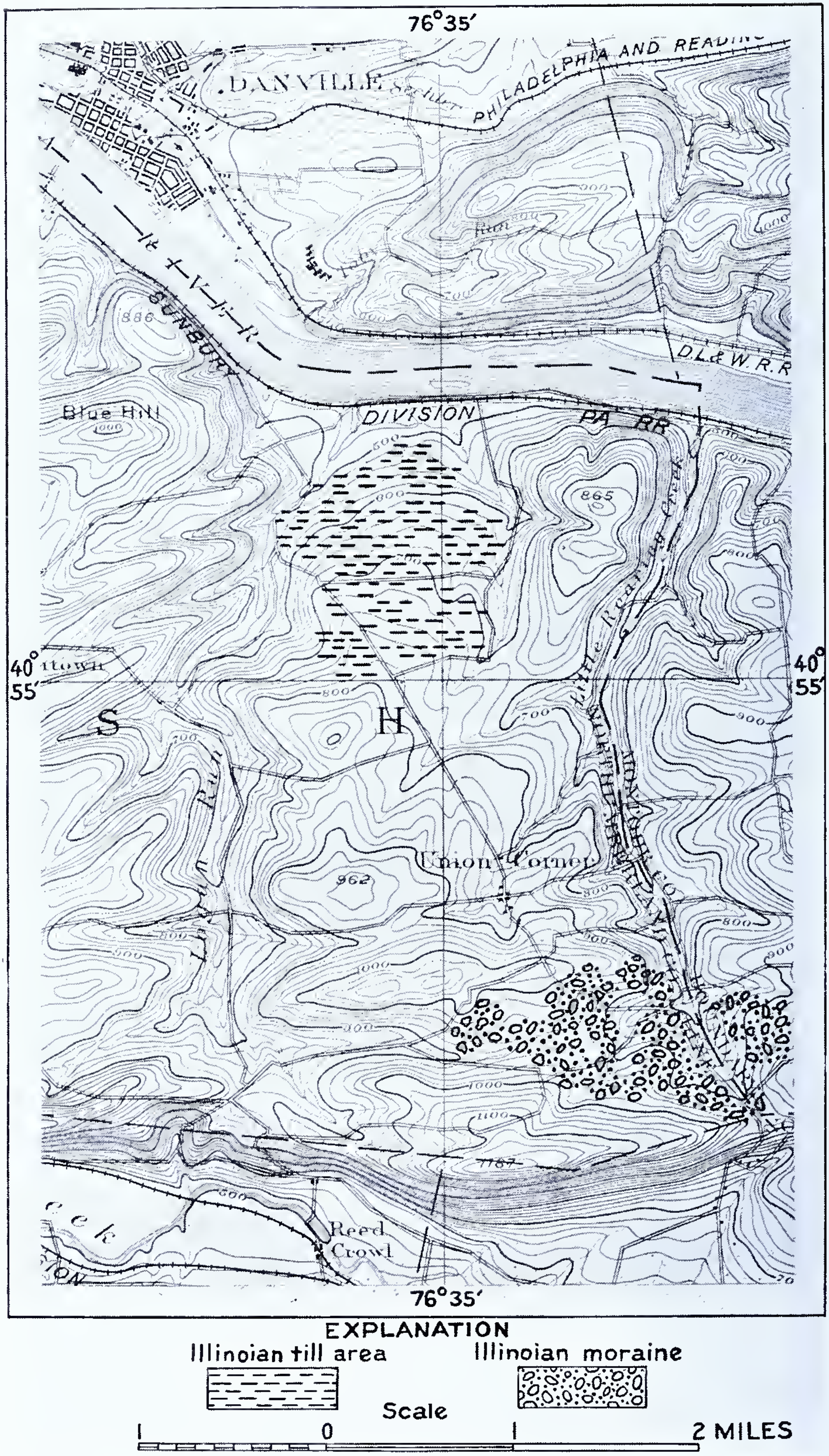

Figure 11. Topographic map of part of Shamokin quadrangle showing Illinoian drift features near Danville.

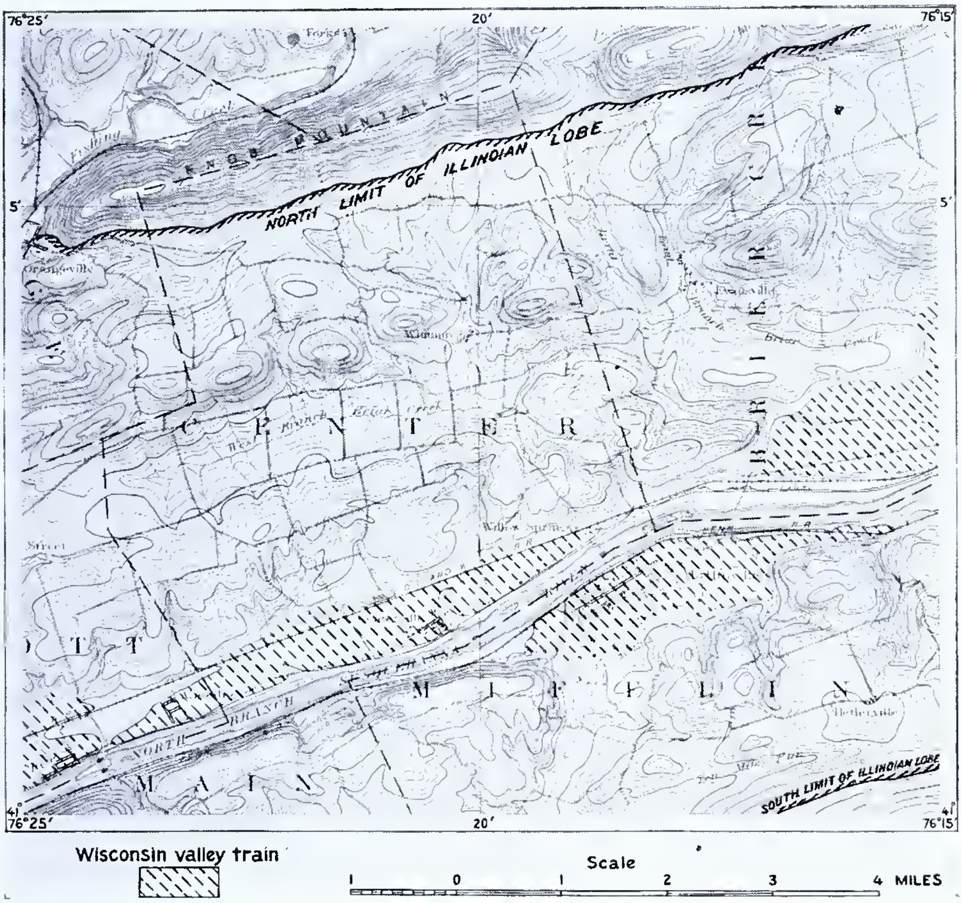

Figure 12. Topographic map of part of Bloomsburg quadrangle showing limits of Illinoian ice lobe in North Branch between Lee and Nescopeck Mountains.

The Illinoian drift is a rather scanty deposit on the south side of Susquehanna River along the base of Nescopeck Mountain, and the ice seems to have done considerable sculpturing of the rock surface there. The drift is thin also on the north side between the Susquehanna valley and the west branch of Briar Creek, from Berwick westward, except near the head of the creek. Railroad cuts there and westward into Light Street expose 10 to 20 feet of drift. West from Light Street along both sides of Fishing Creek the rock surface seems to have been sculptured by an ice movement from E-NE to W-SW. This sculpturing may have yielded material for the deposits near Buckhorn, noted above.

Nescopeck basin. The Susquehanna drainage basin was invaded by ice lobes extending westward from the Lehigh drainage basin in the district south of Nescopeck Mountain. One of these lobes occupied the valley of Nescopeck Creek. The drift in this valley bears a striking resemblance to the Illinoian drift of the Susquehanna valley, and is tentatively referred to the Illinoian stage of glaciation.

The Nescopeck ice lobe lay south of Nescopeck Mountain and extended westward from the border of the Wisconsin drift near St. Johns about to the place where the creek turns northward to pass through a gap in Nescopeck Mountain, or a distance of 9 miles. Its width was about 4 miles at the border of the Wisconsin drift, but scarcely 2 miles near its western terminus.

At its place of emergence from beneath the Wisconsin drift north of St. Johns the drift of this lobe is present up to at least 1400 feet above sea level and much of the area occupied by the lobe west from there is above 1000 feet. The thickness of the ice in this lobe thus seems likely to have been considerably less than in the adjacent part of the Susquehanna lobe.

The drift is a red clayey till very similar to that of the Illinoian drift of the Susquehanna lobe. It forms a nearly continuous sheet along the north side next to Nescopeck Mountain, and some wells have penetrated drift to a depth of 20 to 30 feet. But in the axis of the lobe along Nescopeck Creek, and in the district to the south the drift is very scanty, and the ice appears to have been an eroding rather than a depositing agent.

Greenwood Valley. Indication of an Illinoian ice lobe in the district north of the North Fork of Susquehanna River was noted in Greenwood Valley, a lowland extending westward from Green Creek at Rohrsburg to Little Fishing Creek below Millville. The main flow of ice into this lowland probably came from the east over a ridge 1100 to 1200 feet above sea level between Fishing Creek and Green Creek, for this ridge is strewn with boulders and cobbles at all elevations between Stillwater

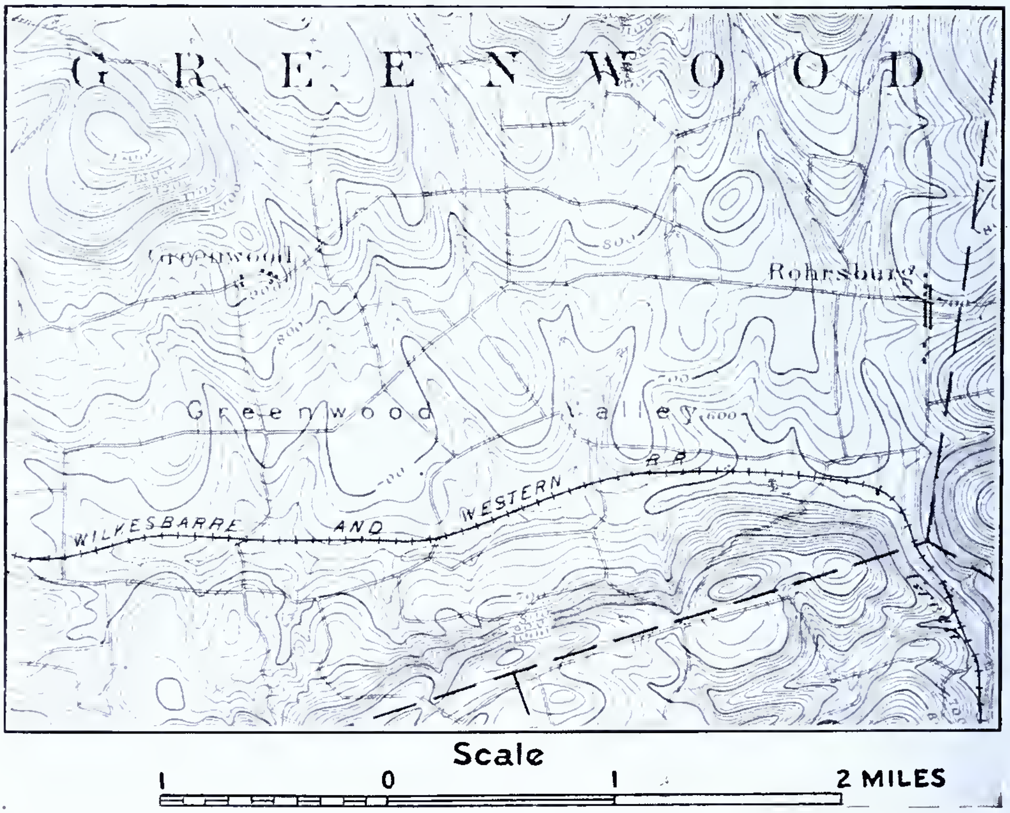

Figure 13. Topographic map of Greenwood Valley in Bloomsburg quadrangle.

and Rohrsburg. There may also have been ice movements down Green Creek and Little Fishing Creek, for their headwaters carry considerable drift, and cobbles are present all along the valleys to a height of 100 feet or more above the valley bottoms. The Greenwood Valley lowland has an altitude below 800 feet in a strip about 2 miles wide (Figure 13). The bordering uplands to the north and to the south rise more than 300 feet above it. There are deposits of red till over a considerable part of this lowland, but the bordering uplands seem to be nearly free from drift. There is also scarcely a trace of drift, so far as the writer was able to discover, from Little Fishing Creek westward to the vicinity of the West Branch of Susquehanna River. The ice lobe seems, therefore, to have had its western terminus at the valley of Little Fishing Creek.

Uplands in eastern Lycoming County and northern Columbia County in the headwaters of Green, Little Fishing and Little Muncy creeks as far south as the vicinity of Unityville carry deposits of red drift that seem referable to the Illinoian stage of glaciation. The highest points thus covered are probably fully 1300 feet above sea level. The ice appears to have extended from there down Little Muncy Creek to the West Branch of Susquehanna River. But there seems to have been very little extension over the district south of Little Muncy Creek.

ILLINOIAN GRAVEL TRAIN ON THE SUSQUEHANNA BELOW SELINSGROVE

Altitude relations. At numerous points along the Susquehanna Valley below the limits of the Illinoian drift there are rock shelves carrying deposits of gravel and sand in which granite and other erratic pebbles of glacial derivation are present. These deposits appear to be a valley train connected with the Illinoian drift. They occur up to about 150 feet above the river at Fishers Ferry, 2½ miles below Selinsgrove, just below the Illinoian drift limit, but within a few miles down stream they drop to about 120 feet above the river. From there down to the head of the Susquehanna gorge near Creswell they stand 80 to 100 feet above the river, the general height being about 100 feet. The rock shelves on which these deposits are preserved have a slight difference in height above the river, being in places only 60 feet while elsewhere they are fully 100 feet above it. It is probable that the river had cut to within 50 to 60 feet of its present level along this part of its course before the deposition of gravel took place. In that case the deposits rest in part on what was then the river bed and in part on low terraces on the borders of the channel. It is probable that the filling with glacial gravel was generally up to a height of about 100 feet above the river, but it is now preserved at its full height at only a few places. (See Fig. 14.)

The terraces carrying glacial gravel are well preserved as far down as Creswell Station, about 6 miles below Columbia, Pennsylvania. The river there enters a rock gorge which extends to its mouth, and there is very little preservation of rock shelves or of glacial gravel on its borders. There is also very little terracing of the lower ends of the tributary valleys that enter this gorge, as they are in resistant crystalline and metamorphic rocks. There is thus more uncertainty as to the Illinoian level and gradient here than in the part above the gorge. The slight deposits that seem referable to drainage at the Illinoian stage are 100 feet or less above the river.

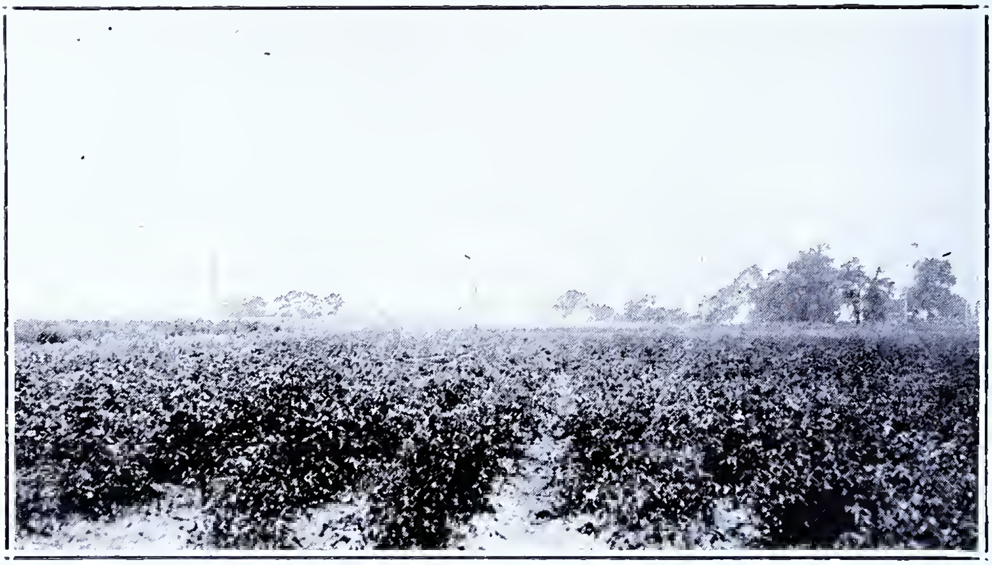

Figure 14. Terrace near Harrisburg 100 feet above the river. Underlying deposit 20 feet thick on river side thins to feather edge away from river.

The distance from the Illinoian drift border to the mouth of the Susquehanna River, at Havre de Grace, is about 125 miles, of which the lower 40 miles is within the gorge. In the 85 miles to the head of the gorge the river has a fall of 210 feet, from 410 feet to 200 feet above sea level or about 2½ feet per mile. It reaches tidewater 5 miles from the mouth, thus leaving 35 miles for the fall of 200 feet within the gorge, or about 5.7 feet per mile. The Illinoian gravel train has a gradient similar to that of the present stream as far down as the head of the gorge, as already indicated, but whether it had as steep a gradient as the present stream in its passage through the gorge is not so clearly established.

Relation to coastal plain formations. It has been determined by students of the Atlantic coastal plain deposits that the Sunderland shore line stands about 160 feet above sea level at the mouth of the Susquehanna River, and the Wicomico shore at about 100 feet above sea level. They are both referred to the Pleistocene epoch. Which of them has the better correlation with the Illinoian stage is a matter of dispute. It is also a question whether the diastrophic movements that uplifted these marine shore lines are to any marked degree dependent upon the weighting effect of the ice sheet. Furthermore, owing to removal of the ocean water to form the ice sheets the sea level should have been at a low stage at the time of culmination of the ice sheets. High marine levels thus seem more consistent with interglacial than with glacial stages. The present writer does not, therefore, seek to make a strict correlation of the Illinoian gravel train with a marine shore line, but merely to determine which shore line seems to be nearest it in age. To this end attention was directed to the kind of material found in each of these shore lines near the mouth of the Susquehanna, and to the degree of erosion each has suffered.

It is found that the Wicomico shore line for several miles each side of the mouth of the Susquehanna River carries numerous indurated sandstones and quartzites from Paleozoic formations crossed by the Susquehanna above the head of the gorge (Fig. 15). The red Medina quartzite is a conspicuous rock, and is present in sizes up to small bowlders. There is a less conspicuous content of Paleozoic rocks in the Sunderland shore line. In fact search is necessary to discover clastic rocks of any sort, the great preponderance of pebbles being vein quartz. The constitution of the rocks in the Wicomico shore line thus seems more consistent with a derivation from the Illinoian gravel train than does the constitution of the Sunderland shore line.

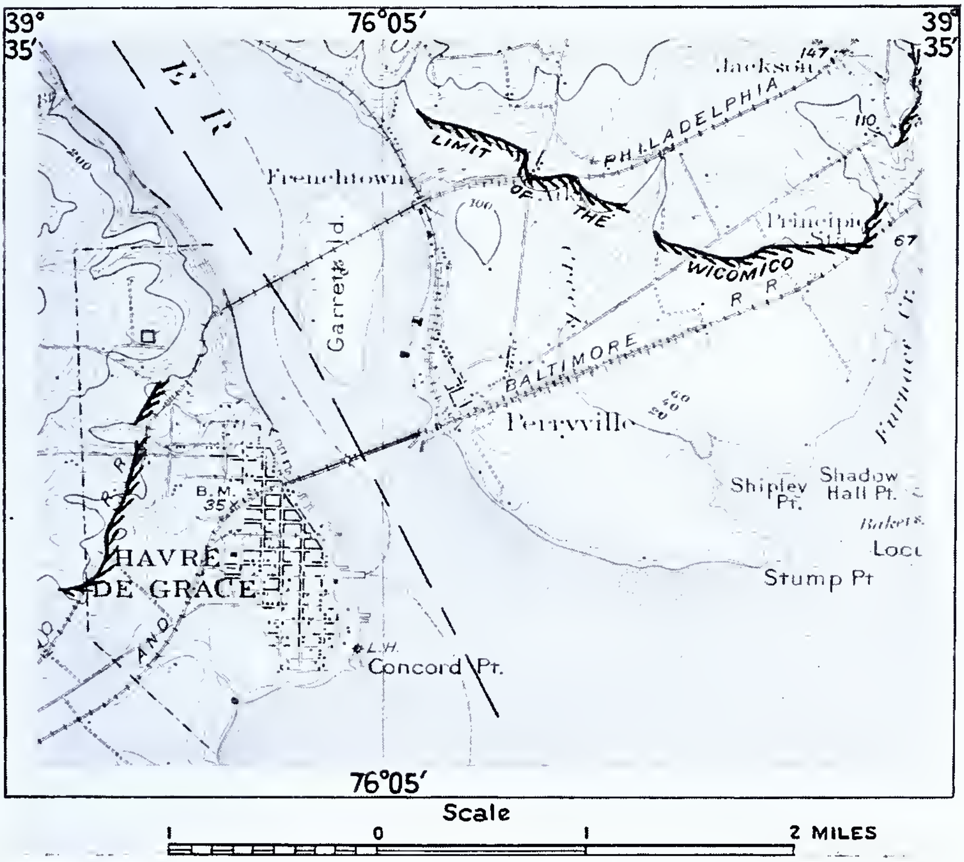

Figure 15. Topographic map of part of Havre de Grace, Maryland, quadrangle at mouth of Susquehanna River showing marine terraces.

The erosion of the Sunderland shore line is so great as to make it a difficult feature to identify, whereas the Wicomico shore line can be easily identified as a shore feature (Figure 15). It has, however, suffered considerable erosion. The degree of erosion seems to the writer to be comparable to that displayed by the Illinoian terraces bordering the Susquehanna above the gorge. The similar degree of erosion and the likeness in rock material thus seem to fall in with the similar altitude above the present river and present sea level in favor of correlating the Wicomico shore line rather than the Sunderland with the Illinoian gravel train in the Susquehanna Valley.

So far as the deposits within the gorge bear on the question they seem to favor a rude parallelism of the Illinoian gradient with the present river gradient. Thus at Safe Harbor, 5 miles below the head of the gorge, remnants of a gravel filling in the mouth of Conestoga Creek stand 90 to 100 feet above the river, and the same condition was noted at the mouth of Fishing Creek 12 miles farther down. At the mouth of Octoraro Creek, 9 miles from the mouth of the river and 4 miles above the head of tide water, there is a narrow terrace or rock shelf, carrying a deposit of river rubble. The deposit is about 5 feet thick and stands 107 to 112 feet above sea level. It contains red quartzite pebbles, probably Medina. A boulder of quartz conglomerate 3 feet long and 18 inches thick included in it probably came from the ledges at Chickies, above Columbia. The altitude of this deposit is about 80 feet above the river, and about 10 feet above the Wicomico shore line at the mouth of the river. Above Conowingo, Md., and at Peach Bottom, Pa., there are deposits of gravelly material in recesses of the east bluff up to an altitude about 70 feet above the river, but there is no terrace at their upper level and the original filling may have been somewhat higher. They may be referable to the Illinoian gravel train.

From the above features and conditions the writer thinks there is warrant for giving the Illinoian gravel train a closer relation to the Wicomico than to the Sunderland shore line.

Character of the deposits. The deposits in this glacial gravel train are composed only in part of material derived from the drift, there being a great deal of rubble derived from projecting rock ledges along the course of the stream. The material derived from the drift is generally well rounded through long transportation in the stream, but material locally derived may show but little rounding or wear by stream action. One of the surprising features is the number and the regularity of distribution of granitic pebbles, usually gneiss. In practically every exposure examined from the Illinoian border down to the head of the gorge a few minutes search would reveal their presence. As there are no ledges of granite or gneiss along this part of the Susquehanna valley, the granitic pebbles are certainly of glacial derivation. They are commonly less than 4 inches in diameter. An occasional granite boulder was noted, the largest being 1½ feet in diameter found near McClellan.

Estimates of the percentage of local material in the deposits of gravel along the Susquehanna valley in the vicinity of Harrisburg have been made by members of the Pennsylvania Geological Survey, from which it appears that about 95 per cent is from local formations, leaving only 5 per cent to be brought in from a distance. The amount of material from outside the Susquehanna drainage basin, and clearly of glacial derivation, appears to form scarcely 1 per cent of the deposit.

ILLINOIAN DRIFT OF THE WEST BRANCH ABOVE MUNCY

General relations. Along the West Branch of Susquehanna River between Williamsport and Watsontown, and in lowlands bordering some of its tributaries, there are deposits of reddish till which are tentatively referred to the Illinoian stage of glaciation. This reference is made because of the moderate degree of erosion and weathering the drift has suffered. In places features of a subdued morainic type are preserved. The drift also forms a continuous and somewhat uniform though relatively thin cover on rather steep slopes which would scarcely retain drift of greater age than Illinoian. The drift also was brought in after the Susquehanna Valley and its main tributaries had been cut nearly to the level of the present streams.

As exposed outside the limits of the Wisconsin drift the Illinoian drift seems to be mainly restricted in this drainage basin to the lowlands south of the Allegheny Front. There are, however, patches of till and scattered boulders and cobblestones on the Allegheny tableland outside the Wisconsin drift border in Lycoming County, as indicated below, which may be of Illinoian age. The ice movement which brought in the drift under discussion seems to have passed over the Allegheny Front in southern Sullivan County west of North Mountain into the drainage basins of Muncy and Little Muncy creeks, and then to have taken a westward course along lines controlled by the trend of prominent ridges and intervening lowlands. There seems to have been a movement southwestward along the south side of North Mountain into Little Muncy drainage basin from the headwaters of Fishing Creek. North Mountain was probably overridden by the Illinoian ice nearly to its west end. Boulders and cobbles occur on the crest at nearly 2300 feet where it is crossed by the road from Nordmont to Wilkes-Barre. A conglomerate boulder was found there in which glacial planing has been so strong that the pebbles have been ground down to match the matrix.

The lowlands carry the main deposits of drift, but it is probable that the ice was thick enough to cover nearly all the ridges between the Allegheny Front and the Susquehanna Valley as far south as the Muncy Hills. This range of hills seems to have stood above the ice. Bald Eagle Mountain, which comes to the west bank of the Susquehanna opposite Muncy, had ice along its northern and southern borders, but apparently stood considerably above the level of the ice sheet.

Probable lines of flow. The ice coming into the Susquehanna Valley from Muncy and Little Muncy creeks was divided into two lobes at the east end of Bald Eagle Mountain. The northern lobe, as already indicated, passed up the Susquehanna River to the mouth of Loyalsock Creek, and there became merged with ice coming down the creek valley. The flow of ice then continued westward past Williamsport at least to the mouth of Lycoming Creek. The southern lobe passed westward down the Susquehanna between Muncy Hills and Bald Eagle Mountain to Montgomery. Here another division took place, one part continuing westward along the south base of Bald Eagle Mountain, and the other taking a southward course along the river. An isolated part of the Muncy Hills lying west of the river just below Montgomery caused this division. It is a question whether this prominence was completely surrounded by ice at the Illinoian stage. The Illinoian ice seems to have extended south along the Susquehanna to the base of White Deer Ridge at Allenwood on the west side of the river, and about to Watsontown on the east side.

The northernmost of the westward lines of flow followed closely the base of the Allegheny Front from the border of the Wisconsin drift at the valley of Big Run, north of Tivoli, westward past Huntersville and Loyalsock to Warrensville. The part between Loyalsock and Warrensville was included by H. Carvill Lewis in the "Terminal Moraine," but it lies well outside the limits of the Wisconsin drift, and has the characteristics of the older drift of supposed Illinoian age. To what degree this ice flow at the base of the Allegheny Front was merged with the main lobe along the part of the Susquehanna Valley adjacent to it is not apparent. There probably was a complete union at the valley of Loyalsock Creek, but a chain of hills to the east and west of the creek, midway between the Allegheny Front and the Susquehanna Valley, may have caused separate lines of flow on their north and south borders. The ice along the Allegheny Front was on higher ground than that in the Susquehanna Valley, so is likely to have been correspondingly thinner. There also is markedly less drift here than along the borders of the Susquehanna River. But it is not so scanty as on the intervening chain of hills. The till is in strips and patches several feet thick, but the hills carry only scattered stones that are referable to glacial action.

It seems very probable that an important ice flow came down Loyalsock Valley through the Allegheny Front in a southward course to meet the westward flow from the Muncy drainage along its south base. The movement beyond the junction of these ice flows may have been mainly southward down the deep Loyalsock Valley, with only a weak one to the west past Warrensville.

There appears also to have been a junction of ice flows at the mouth of Loyalsock Creek, in which the southward flow down the creek valley met a westward flow up the Susquehanna River valley. There are features near the mouth of the creek which seem to indicate that the movement down the creek came a little in advance of the westward flow up the river valley. On each side of the mouth of the creek, near the north bluff of the river, there are thick deposits of gravel and sand which appear to be an outwash from an ice lobe in the creek valley. Those on the east side have beds dipping southeastward down the Susquehanna Valley, while those on the west side have a southward dip into the river valley (Fig. 16). The deposits, as determined by hand level, were built up to the same height, estimated to be about 620 feet above sea level on both sides of the creek valley. Those on the west side rest on a rock base only 30 feet above the bed of Loyalsock Creek, and have a thickness of 80 feet. Those on the east are on higher rock ledges and have a thickness of 20 to 45 feet, as shown by open pits and test borings. The deposits seem to have been built up under conditions of discharge down the Susquehanna Valley. But there may have been a rise of 80 feet in the river level during their deposition. Such a rise seems referable either to the encroachment of ice on the part of the valley just below the mouth of Loyalsock Creek, or to the blocking which took place at the junction of the North Branch and West Branch when the Illinoian ice lobe on the North Branch reached there. The deposition of gravel and sand seems to have been completed in advance of the maximum filling of the valley by ice at the former place. These outwash deposits were subsequently overridden by ice, and till was laid down upon them. The till is only a few feet thick on these deposits, but is present in districts immediately adjacent up to an altitude 100 feet above them, or to about 720 feet above sea level. The ice coming in from the east, up the Susquehanna Valley, deposited till up to about this height over the district between Muncy Creek and the mouth of Loyalsock Creek.

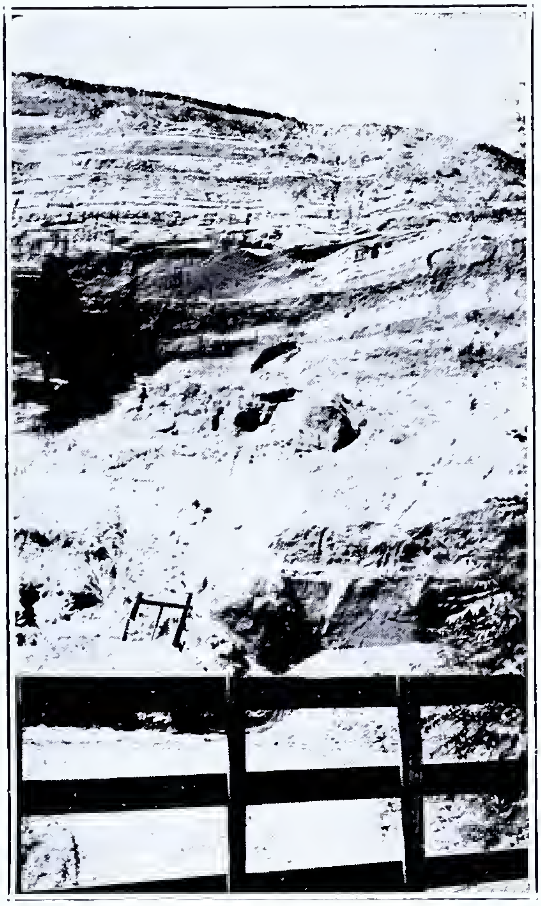

Figure 16. Illinoian outwash gravels near mouth of Loyalsock Creek. Photo by Geo. H. Ashley.

Altitude relations. At the headwaters of Little Muncy Creek, as already indicated, drift of supposed Illinoian age covers uplands south of the Allegheny Front that are estimated to be fully 1300 feet above sea level, and on North Mountain it may have reached 2300 feet. But at the Susquehanna near Muncy the upper limits of a definite sheet of drift are less than 800 feet above sea level. However the upper limit of such a sheet is a little above 700 feet as far west as the mouth of Loyalsock Creek on the borders of the Susquehanna, and to a similar distance west from Muncy on the south side of Bald Eagle Mountain. So the ice may have stood somewhat higher than 800 feet at Muncy. Along the Susquehanna below Montgomery till is present only to about 600 feet.

Thickness of the drift. The thickness of the drift in the district tributary to the West Branch of Susquehanna River exhibits about as much variation as that tributary to the North Branch. There are places where it makes a continuous sheet on the hillside slopes as well as on plains and valley bottoms. Between such places there are large areas with scarcely a trace of drift, and that too in situations where the scantiness can scarcely be referred to post-Illinoian erosion. Around the headwaters of Little Muncy Creek the drift is present on steep slopes. This is the case from Unityville northwestward to North Mountain in the eastern end of Lycoming County. The topography is morainic in the vicinity of Lungerville at an altitude of about 1300 feet, but drift is scanty deep down in the lower ends of tributary valleys. From Lairdsville down to the mouth of Little Muncy Creek near Clarktown there is only a short section, near Moreland, where the drift is conspicuous. For half a mile west of Moreland and for about 2 miles northeast it forms a nearly continuous coating on ground about 100 feet above the stream. Were it not for this drift-covered section one might question the extension of the Illinoian ice down Little Muncy Creek valley, though the course of the valley seems to be in a natural line for the ice to have reached the Susquehanna Valley at Muncy, and carried in the heavy deposits found along the valley both above and below Muncy. Because of the great extension of the Wisconsin ice over Big Muncy drainage basin the strength of the Illinoian ice movement down this creek is not easy to determine. It may have been stronger than that along Little Muncy Creek. It may have contributed the greater part of the drift along the border of the Susquehanna below Muncy.

The strip of Illinoian drift which extends up Susquehanna Valley has its north border banked against the south slope of a range of hills that lies about 3 miles north of the river from Picture Rocks westward to Loyalsock Creek, and, as already stated, the drift is abundant up to an altitude of fully 700 feet, or about 200 feet above the Susquehanna flood plain. It seems to have considerable thickness in the depressions between the hills, and gives these depressions a graded-up appearance (Fig. 17). The altitude of the drift sheet becomes somewhat lower

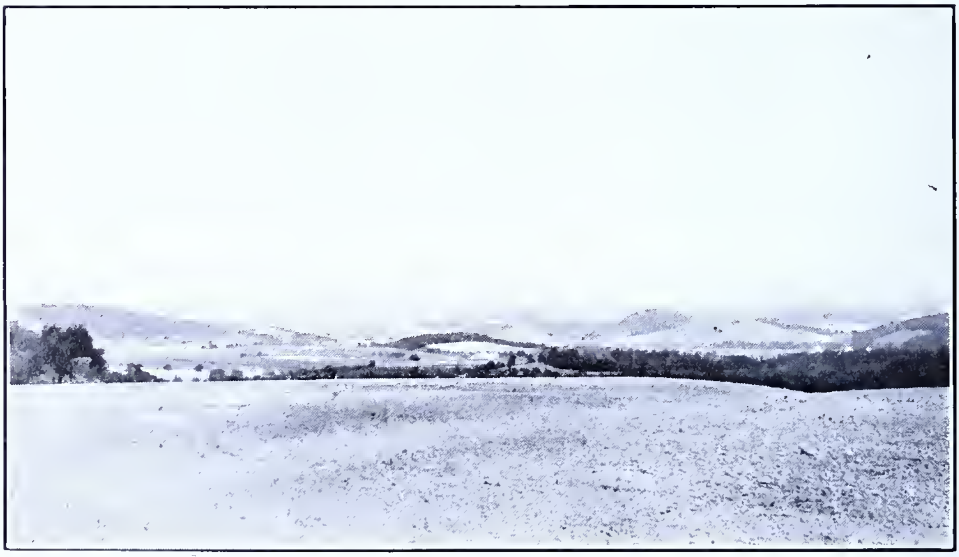

Figure 17. Drift filling amongst rock hills bordering the lower course of Loyalsock Creek. Cobbles numerous in field in foreground. Photo by Geo. H. Ashley.

between Montoursville and Williamsport and is only about 600 feet to the west of Williamsport, near the mouth of Lycoming Creek. The Illinoian ice appears to have extended but little beyond the mouth of this creek. Bald Eagle Mountain rises steeply from the south bank of Susquehanna River in the section occupied by this ice lobe, and its talus so covers the slope as to obscure any effect produced by the ice sheet.

Character of deposits. Aside from the gravel deposits at the mouth of Loyalsock Creek the deposits so far as exposed are almost entirely a reddish clayey till. The surface usually is nearly plane, but saucer-like basins were noted on it northwest of Hall Station on the east side of Tules Run, on the divide between it and Turkey Run. These are of significance in showing that the surface has not been greatly modified by erosion.

ILLINOIAN PONDING ON WEST BRANCH ABOVE WILLIAMSPORT

The part of the Susquehanna Valley immediately above the western end of this ice lobe was examined for evidence as to the height of ponding produced by it. Cobbly deposits were found on gentle slopes along the base of the north bluff for several miles below Jersey Shore as high as the 620-foot contour, or to practically the same height as the outwash gravel at the mouth of Loyalsock Creek, already described. The amount of cobble is such as to indicate ponding at that level for a considerable time, but as in the case of the outwash gravel on the Loyalsock it may have antedated the more complete blocking of the valley by the ice lobe. On the south side of the valley there are alluvial cones where tributaries come down the steep slope of Bald Eagle Mountain, or break through gaps in the mountain. The latter have larger drainage areas and have made more prominent deposits. One of these, Nippenose or Antis Creek, has built a large alluvial fan west of Jersey Shore station of the Pennsylvania Railroad which stands between 620 and 640 feet above sea level (Figure 18). The railroad cuts through it and exposes 27 feet of gravelly material at top, beneath which is a laminated clay extending to the shale rock which is exposed near the base of the cut. The gravel seems to be entirely above the 600-foot level. Its surface is probably nearly 640 feet. South of the railroad the alluvial fan stands above the 640-foot level. It seems to have been built up in connection with a ponded condition of the Susquehanna that reached at least 640 feet above sea level, and probably 660 feet.

Another prominent alluvial fan was formed at the mouth of McElhattan Creek about 6 miles below Lock Haven. This one was built up nearly to 700 feet altitude at the base of Bald Eagle Mountain, but drops down rapidly to the 620-foot level, below which its slope is more gentle (Figure 19). There is likely to have been ponding to at least 660 feet at this place.

Just below the McElhattan alluvial fan, Pine Creek, a large northern tributary of the Susquehanna, which headed within the limits of the Wisconsin terminal moraine, brought in a deposit of glacial gravel. The surface of the deposit is only slightly below 600 feet, or about 75 feet above the low water level of the river. The deposit is coarse gravel and cobble. It is well displayed along the highway leading east from

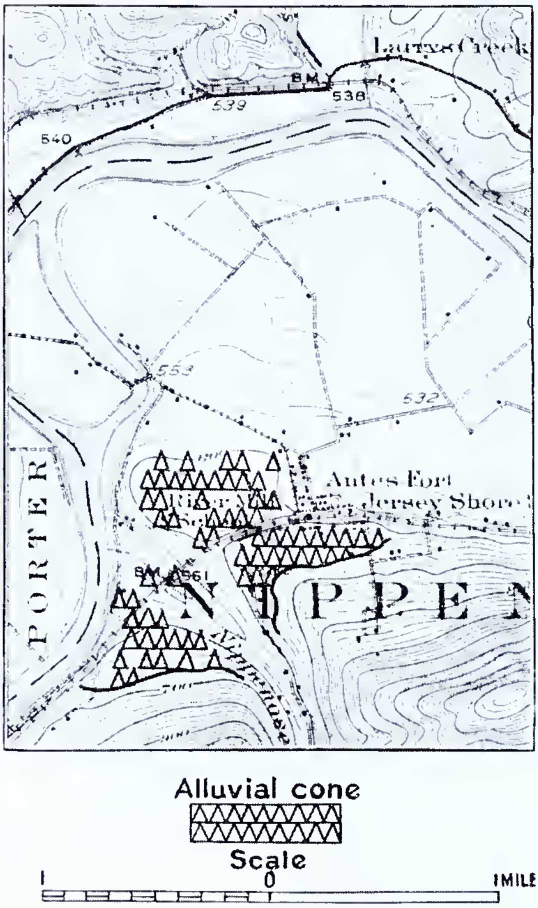

Figure 18. Topographic map showing alluvial fan on West Branch near Jersey Shore.

Avis to Pine Creek. In the village of Avis and for a mile north along the base of the west bluff of Pine Creek, clay deposits are conspicuous up to fully 640 feet. These seem referable to a ponded condition of the Susquehanna prior to the Wisconsin stage of glaciation. In Jersey Shore, just below the mouth of Pine Creek, there is an extensive terrace of cobble in a loamy matrix. It stands above 660 feet and seems to call for a ponding to that height, or 135 feet above the river.

At Lock Haven an important southern tributary, Bald Eagle Creek, enters the Susquehanna River. Cobble deposits are conspicuous in its lower course from Blanchard to Lock Haven at about 660 feet. At Flemington, a southwestern suburb of Lock Haven, there is about 30 feet of gravel whose top is 670 feet above sea level. The valley of Bald Eagle Creek thus seems to have been filled to this level at its mouth to match a similar water level on the Susquehanna. The gravel covers only a few acres and seems to be a small remnant of the original deposit.

Between Williamsport and Lock Haven the features thus indicate ponding to a level a little above 660 feet, and this seems referable to the Illinoian ice invasion of the part below Williamsport. Williams suggested ponding to a level high enough to reach a pass a little above 1100 feet at the head of Bald Eagle Creek, at Dix, at the time the ice

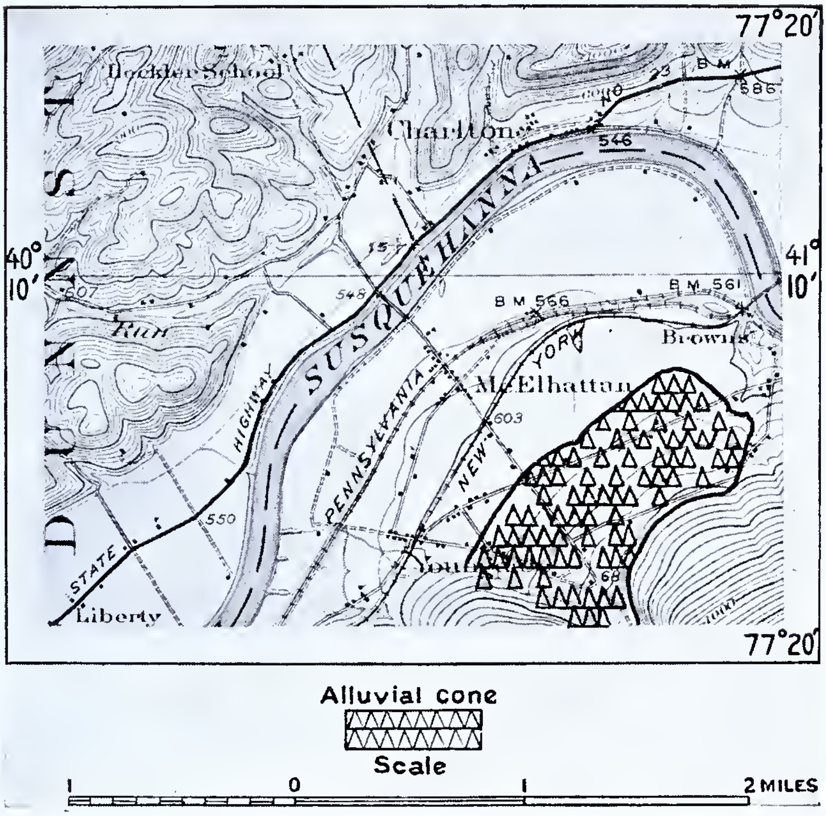

Figure 19. Topographic map showing alluvial fan on West Branch at mouth of McElhattan Creek.

sheet had its greatest extension in this region. This matter will be discussed later in connection with the description of a pre-Illinoian drift which has greater extent than the Illinoian drift in the Susquehanna drainage basin.

ILLINOIAN DRIFT ON THE WEST BRANCH BELOW MUNCY

Probable limits. There is some uncertainty as to how much of the drift on the borders of the Susquehanna below Muncy should be referred to the Illinoian stage of glaciation. That the Illinoian ice followed down the valley as far as Allenwood is inferred from the state of preservation of the drift. A narrow strip of glacial topography, with shallow basins and low swells, is still preserved next to the river. The drift here also was deposited after the Susquehanna Valley had been cut nearly to its present level. It is not rare to find a thickness of 50 feet, and in a few places 80 to 90 feet, of drift in this strip. If the Illinoian is restricted to this narrow strip, its upper limits show a decrease in altitude down the valley, being about 720 feet near Muncy, 640 feet near Montgomery, and 560 feet near the southern end around Allenwood and above Watsontown.

Till is present in two areas just outside this strip, one being on the east side of the river in a lowland south of the Muncy Hills, and the other in White Deer Valley, a lowland that sweeps around the hills on the west side of the river southwest of Montgomery, (Figure 20). In the former area it was noted as far east as the vicinity of Turbot-

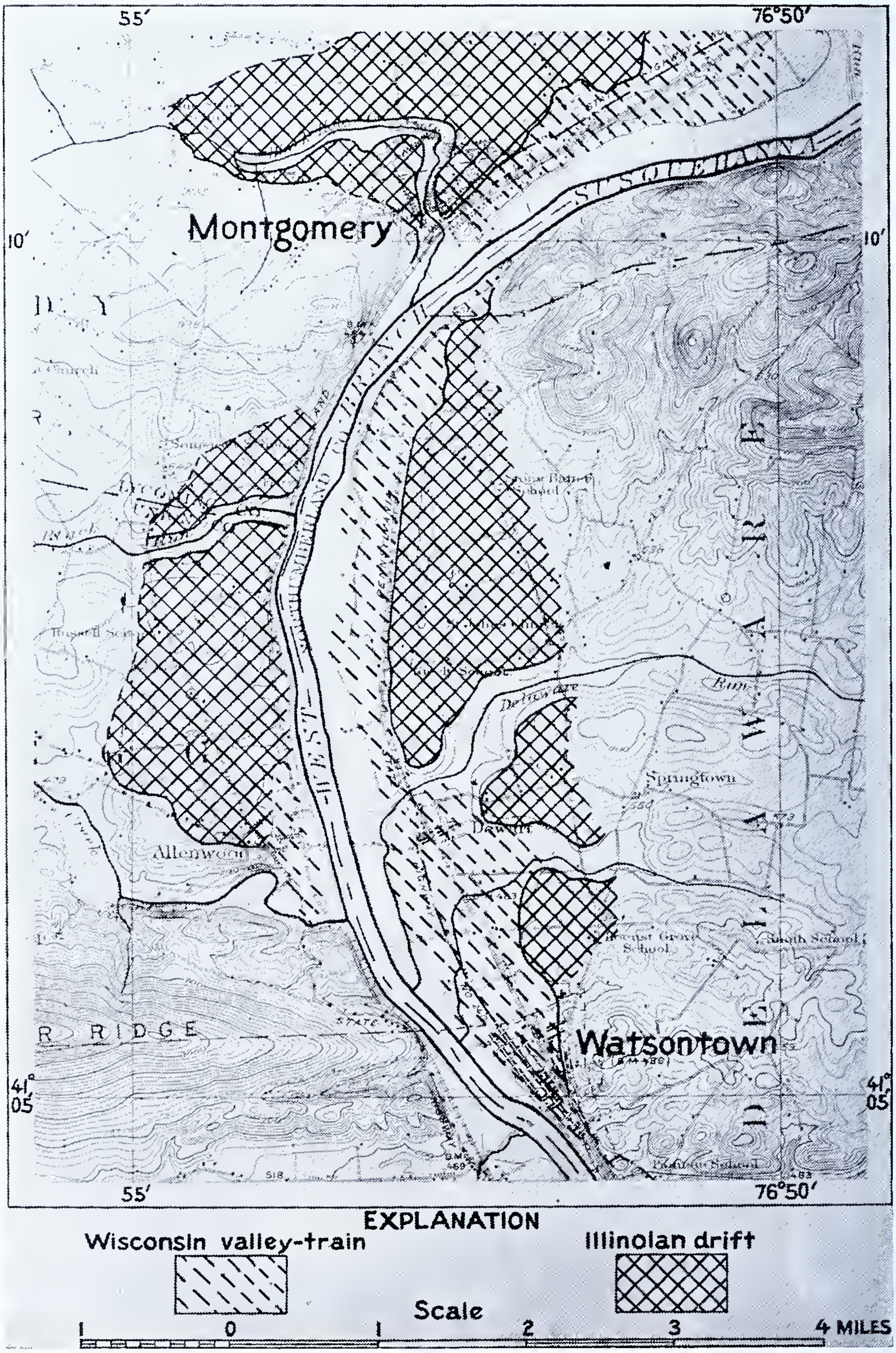

Figure 20. Topographic map of part of Milton quadrangle showing glacial and physiographic features near Montgomery.

ville, about 6 miles from the river. The till is restricted to small patches or strips along the ridges between the small drainage lines, where erosion has been least effective. The remnants thus preserved are very thin, usually between 5 and 10 feet, and the aspect of the deposits, in regard to the weathering and decay of pebbles, seems to favor reference to a pre-Illinoian glaciation. The altitude of the till deposits is generally below 600 feet, or about as low as that of the till along the border of the river that is interpreted to be Illinoian. It is, however, as high at the easternmost exposures, near Turbotville, as in those nearer the river. While the till is preserved only at low altitudes, small erratics are present up to considerably higher altitudes on the slope of Muncy Hills, the upper limit as estimated by I. C. White being 800 feet, and they occur to still higher altitudes on the hills southwest of Montgomery.

In the White Deer Valley, the lowland that sweeps around the hills southwest of Montgomery, till is better preserved than south of the Muncy Hills east of the river, nearly all the surface being covered either with till or a pebbly concentrate derived from it. The drainage lines in it are generally in very shallow valleys with indefinite bluffs or borders (Figure 20). The till is only a few feet thick on the west and south sides of the hills. On the north side, in the drainage of Black Hole Creek, the deposit is heavier, one well a mile northwest of Montgomery having penetrated 80 feet of drift. The altitude at this well is 640 feet, or about the same height as the Illinoian drift on the east side of the river south of Montgomery. It seems highly probable that the Illinoian ice pushed into the Black Hole drainage basin beyond this well, and perhaps reached the divide between the Black Hole and Spring Creek drainage. A swale at this divide is about 650 feet above sea level, and may have carried the glacial drainage from the end of the Illinoian ice lobe in the Black Hole district. It seems an open question whether the drift in the Spring Creek district of the White Deer Valley should be referred to the Illinoian stage. It may belong to an earlier stage and correlate with the cobbly deposits found at higher altitudes on the hills southwest of Montgomery. Such deposits are present nearly up to the highest points, or over 900 feet above sea level. The amount of erosion of the till in the Spring Creek drainage basin appears moderate, though it seems to be greater than is displayed by the Illinoian drift near the river.

Character of the drift. The strip of Illinoian drift along the Susquehanna is more stony and looser textured below Muncy than it is up the river. It is bouldery at all depths as well as on the surface. The part below Montgomery, on the east side of the river, has been given the name "Stony Batter" because of the great number of boulders on its surface. Their exceptional abundance here was noted by White as follows:[1]

> Where Hamilton valley debouches into West Susquehanna, near the north line of Delaware Township, a vast deposit of waterworn boulders, gravel, and other trash borders the east bank in a broad terrace 175 feet above the river (635 feet A.T.). This terrace rises precipitously above a lower one 135 feet, and is a mass of boulders up to 2½ to 3 feet in diameter. It holds the altitude of 635 feet for a mile south, then begins descent to McKane's Corners where it is 545 feet.

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[1] Pennsylvania Second Geol. Surv. Report, G 7, p. 328.

The drift here fills a gap in the Muncy Hills, at a place where the Susquehanna makes an abrupt turn from a westward to a southward trend. Just above this bend the south bluff is very precipitous to a height of 350 to 400 feet above the river, and some of the hills fronting on the river have been cut away past former summits or crests. This seems likely to have been due to the erosion or scouring by the south edge of the Illinoian ice tongue. The material thus cut away would naturally be dumped at the southward turn in the valley and thus account for the "Stony Batter" or bowldery drift laid down in the gap in the Muncy Hills. Although called a terrace by White the deposit has an undulating surface with basins and low swells, of subdued morainic type. The boulders are plentiful as far south as Dewart. The lower terrace noted by White marks the level of a valley train of Wisconsin glacial gravel, 40 feet above the river. It barely reaches 500 feet above sea level at this place, while the river here passes below 460 feet.

ILLINOIAN PONDING IN LOWER END OF THE WEST BRANCH

A ponded condition seems to have existed in the valley of the West Branch of Susquehanna River below the terminus of the Illinoian ice lobe. There is no train of glacial gravel in this part of the valley except that connected with the Wisconsin glaciation. This gravel train is only about 40 feet above the river. On the valley slopes, above the level of the Wisconsin filling, sand deposits are in places conspicuous, and these may have been laid down in the ponded waters of the Illinoian glacial stage. They have been shifted eastward to some extent by the wind and thus reach various heights at different points along the valley. They are most conspicuous where there is a gentle rise into low hills bordering the river, and most of the sand is within 100 feet above river level. But the ponding probably filled the valley about 150 feet above the river.

The ponding probably reached to the level of low passes between the Susquehanna and valleys west of it that would carry the drainage around the end of the North Branch ice lobe. The topographic map of the Sunbury quadrangle shows a pass just above 580 feet in a lowland that extends westward from the West Branch at Winfield to Penns Creek below New Berlin. (Figure 21). The present divide is crossed by an erosion channel opened by water discharging from the Susquehanna to Penns Creek. It carried a cobbly deposit across the divide into the valley of a small eastern tributary of Penns Creek. The bed of the channel is less than one-fourth mile wide at the divide, and thus seems small for a line of discharge for the melting ice lobe and the part of the watershed of the West Branch of Susquehanna River outside the ice, but it seems to have functioned as an outlet for some of the ponded water, and serves to show the probable upper limit of the ponding. It seems not improbable that some of the ponded water found escape along or beneath the edge of the North Branch ice lobe.

The lower end of Penns Creek was covered by the North Branch ice lobe, and may have caused such part of the drainage as did not find escape along the edge of the ice lobe to flow westward to Middle Creek and thence to the Susquehanna outside the limits of the ice

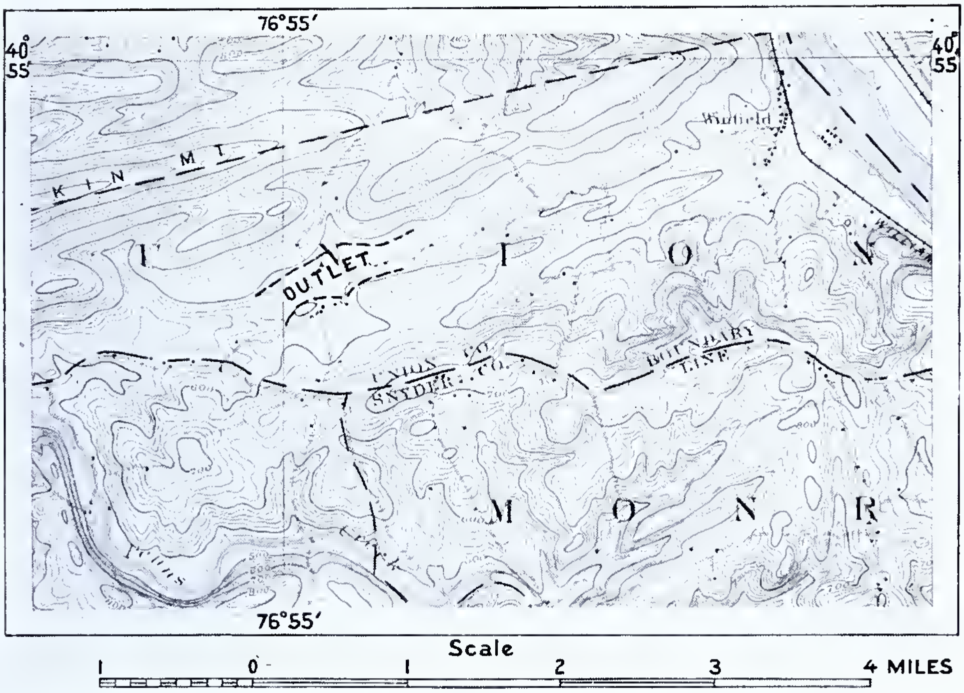

Figure 21. **Topographic map showing Illinoian spillway between Susquehanna River and Penns Creek, west of Winfield.**

lobe. Two very narrow valleys lead west from Penns Creek to Middle Creek just outside the limits of this ice lobe, and connect with Middle Creek at Kreamer; in one the summit is below 620 feet above sea level, and in the other between 620 and 640 feet. Evidence is not clear of a strong flow of water across the divides in them. Instead the surface material in the vicinity of the divides is clayey. They may, however, have served as spillways for part of the water ponded above the North Branch ice lobe.

Bearing on limit of ponding above Williamsport. It having been determined that 580 feet is the probable extreme limit of the ponding in the lower end of the West Branch of the Susquehanna above the North Branch ice lobe, it remains to consider the probable height to which ponded water is likely to have risen in the part above Williamsport. The upper limit of the Illinoian drift in the part of the West Branch valley above Muncy, as already indicated, is but little above 700 feet above sea level. It seems probable that the border of the ice next to Bald Eagle Mountain was but little above this level, either on the north or the south slope or at the eastern end of the mountain opposite Muncy. This being the case there seems to have been no occasion for ponding above Williamsport to have been any higher. In fact, it seems likely that the ponding would have been for much of the time a little lower than the full limit of the height of the ice border.

ILLINOIAN DRIFT ON ALLEGHENY MOUNTAIN IN LYCOMING COUNTY

A sheet of till is present for a few miles outside the limits of the Wisconsin drift in northern Lycoming County which probably is of Illinoian age. It is best exhibited in a farming district in Cogan

House Township in the headwaters of Larrys Creek where road cuts are numerous and much of the land is under cultivation. The altitude of this farming district, as shown by the Trout Run topographic map, is between 1300 and 1800 feet above sea level. Exposures of till are to be seen about half a mile southwest of the Susquehanna Trail near Steam Valley Mountain at an altitude above 1700 feet. They are also numerous from there southwest for 2 miles or nearly to Cogan House, and also westward for 4 miles to Beech Grove School. Cobble deposits are present farther west in the vicinity of White Pine, and from White Pine to Brookside in the headwaters of Second Fork of Larrys Creek. The till is over 16 feet thick in some of the road cuts. It is of reddish color, and seems to exhibit weathering consistent with Illinoian age. The amount of erosion, or rather the degree of preservation, of the deposit is such as to indicate an age no greater than Illinoian. It is not so clayey as the Illinoian drift near the Susquehanna Valley, the matrix being sandy. It is also more thickly set with coarse stones. Many of the stones are well rounded by water action, even those a foot or more in diameter.

It seems probable that the Illinoian ice extended only to the south edge of this farming district, and that the higher land to the south, points on which reach 2100 feet, was not covered. But the Illinoian ice may have covered nearly all the land on the north of the farming district even where over 2000 feet above sea level. The Wisconsin drift reaches an altitude of 2160 feet on Bodine Mountain in the northeast corner of the Trout Run map. The Illinoian ice, being more extensive than the Wisconsin, is likely to have overridden the highest areas to the north of the Cogan House farming district.

A farming district in Gamble Township east of Trout Run lies just outside the Wisconsin drift border and carries drift of probable Illinoian age. Its altitude is 1200 to 1600 feet. Till is thin and patchy, but bowlders abound in this district. The Illinoian ice may have been limited to Mill Creek drainage and failed to cover the range of hills east of Lycoming Creek in the vicinity of Trout Run, points on which exceed 2000 feet above sea level.

ILLINOIAN FLUVIAL PLAIN ON JUNIATA RIVER

The Juniata Valley was examined as far up as Tyrone in order to compare the features of a drainage line whose watershed is just outside the limits of glaciation with those of the Susquehanna which was so largely covered by ice at several stages of glaciation. Especial attention was directed to finding on the Juniata an equivalent of the Illinoian terrace of the portion of the Susquehanna valley below the limits of the Illinoian drift.

Deposits of waterworn material were found at various heights on the valley slopes and to a slight extent outside and above the limits of the definite river trench, as well as on terraces down in the trench. Those outside the river trench are probably of pre-Pleistocene age, as they occur up to levels more than 400 feet above the river. Between these and the highest well-defined terrace are deposits that may fall in the early Pleistocene. The highest definite terrace appears to fit in well with the Illinoian terrace of the Susquehanna in its altitude above the stream.

Where Frankstown Branch and Little Juniata River join to form the Juniata River, near Alexandria, a well-defined terrace of probable Illinoian age is 800 feet above sea level and 120 feet above the river. (Figure 22). Below here the river makes a rapid descent of 60 feet through a narrow gorge to Huntingdon. But the stream at the Illinoian stage seems to have made a descent of only 20 feet and occupied the well preserved terrace at about 780 feet on the west side of the river above and opposite Huntingdon. The river cuts through a mountain range below Huntingdon and makes a great loop below Mt. Union. On the inner curve of this loop river deposits are found in a continuous sheet on the slope up to a level 140 feet above the river, or 660 feet above sea level and scattered pebbles to 80 feet higher. The Illinoian limit seems to be at about 660 feet. Along the rather wide-

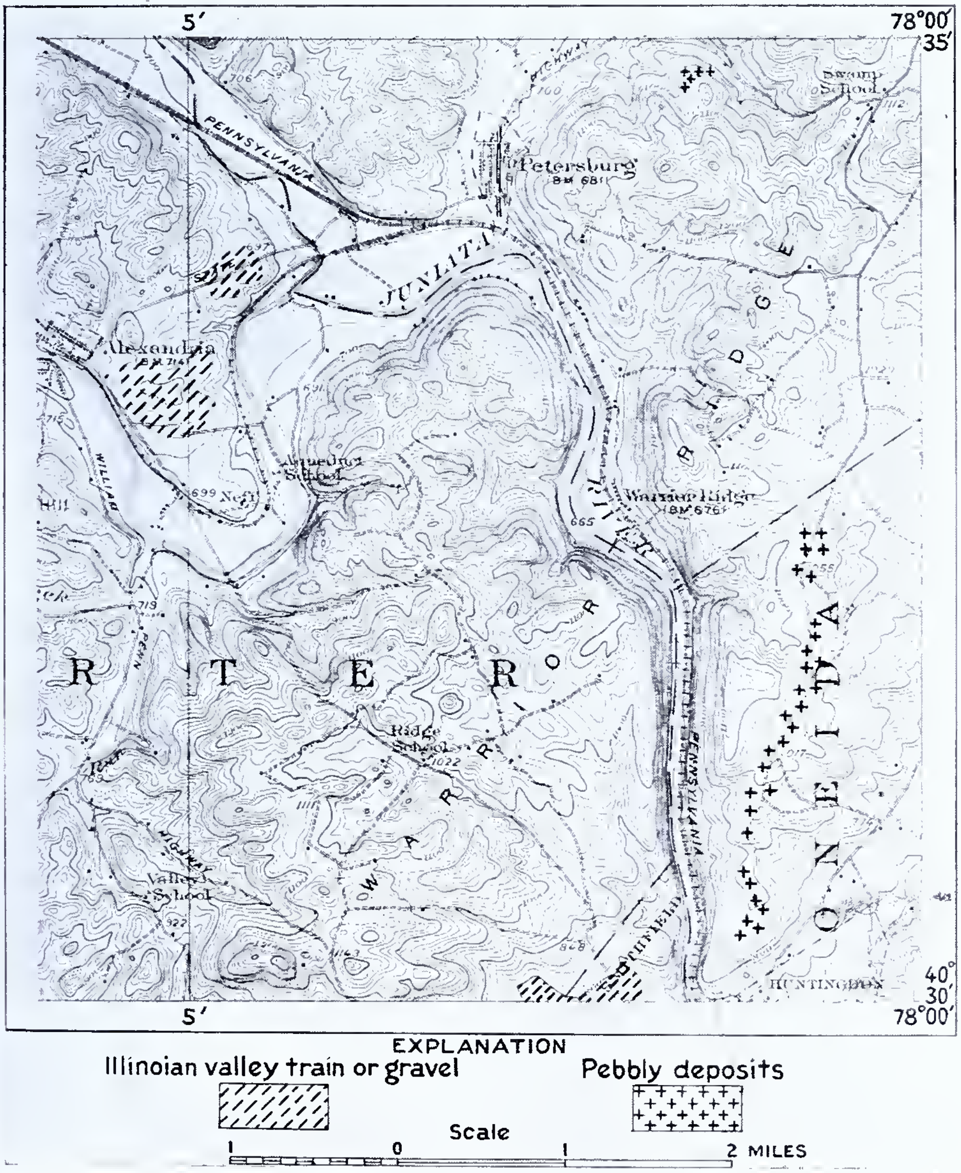

Figure 22. Topographic map showing Pleistocene and pre-Pleistocene gravel deposits near Alexandria and Huntingdon.

open part of the valley between Mount Union and Lewistown there are remnants of fluvial deposits on terraces up to 140 feet or more above the river. Around Lewistown they reach fully 160 feet above it, or to 620 feet above sea level. Between Lewistown and Mifflintown the river descends in a narrow valley through a mountain range and then enters another area of less relief. Gravel deposits are conspicuous on low hills bordering the river between Mifflintown and Port Royal up to about 170 feet above the stream, or 580 feet altitude. But among and back of these hills are flat areas at about 500 to 520 feet which seem more likely to represent the level of the river at the Illinoian stage. (Figure 23). The river turns east at Port Royal and for about 10 miles flows through a broad open valley with wide terrace remnants at about 500 feet, or 110 to 120 feet above the river. (Figure 24).

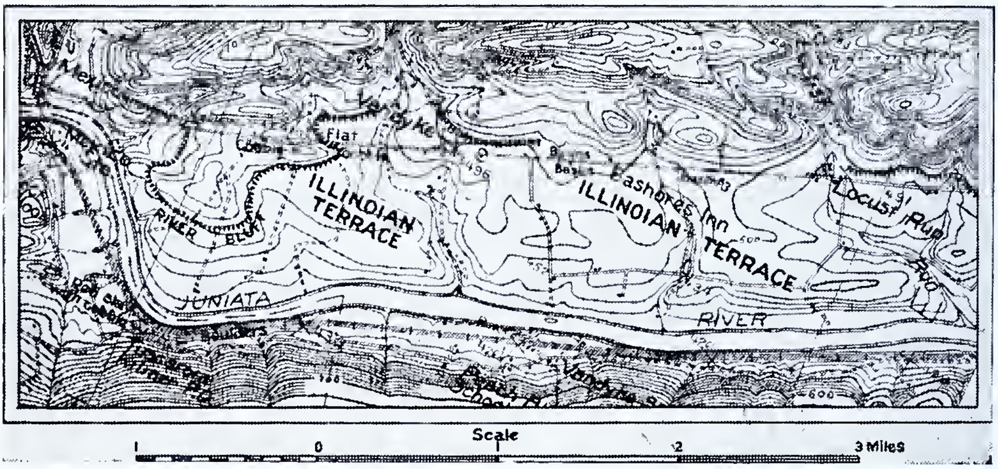

Figure 23. Topographic map of Juniata Valley below Mexico showing gravel deposits of Illinoian and pre-Illinoian age.

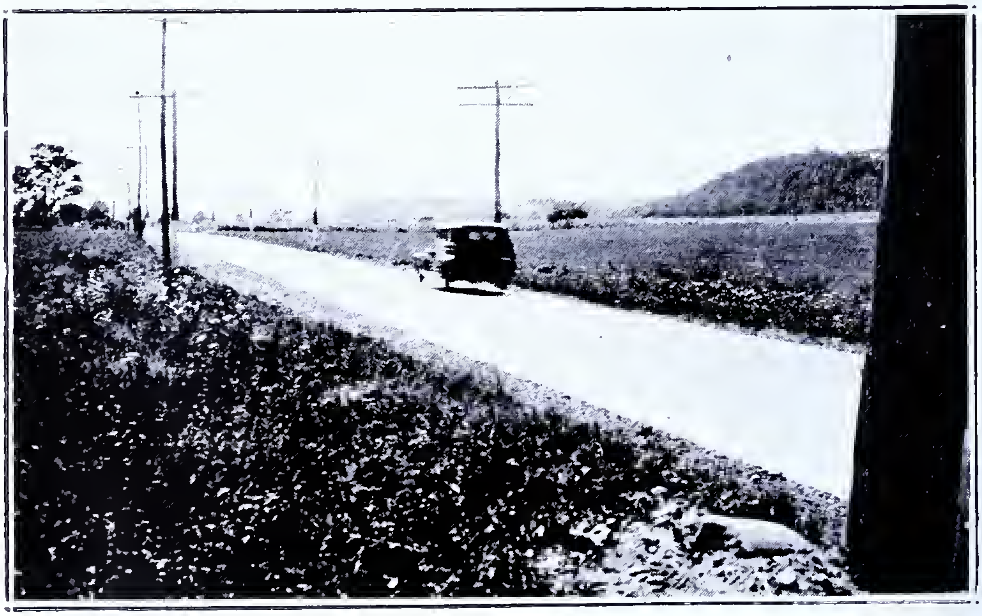

Figure 24. Illinoian gravel plain east of Thompsontown.

These terraces carry gravelly deposits which in places are over 50 feet thick. Shallow basins in the gravel seem to mark inequalities of deposition rather than sinks due to underground drainage. The river then turns southward through a mountain range just above Millerstown, and another below that village, and passes around the end of a third above Newport. There are narrow terrace remnants along the east side below Millerstown, the best defined being below 460 feet or scarcely 80 feet above the river. Terraces in the vicinity of Newport are also between 440 and 460 feet, and between 80 and 100 feet above the river. They hold a level of 440 feet as far down as Losh Run where the altitude is 100 feet above the river. The terrace of glacial gravel on the Susquehanna just below the mouth of the Juniata, in Duncannon, is also 440 feet, and 106 feet above the river.

PRE-ILLINOIAN DRIFT IN THE SUSQUEHANNA DRAINAGE BASIN

Nature of the evidence. Outside the limits of the Illinoian drift as above outlined there are traces of what appears to be a much earlier glaciation. The deposits are very scanty, consisting generally of scattered erratics, but embracing also patches of till. There are also places where the ice appears to have planed off the outcropping edges of coal beds and other rock formations, removing the decayed and deeply weathered surface portion and exposing the relatively firm and but slightly altered rock. The discovery of these features is to be credited to E. H. Williams and his assistants in the investigations made some 30 years ago. Brief accounts of these studies were published by Williams soon after they were made, but the results are more fully presented in his paper *Pennsylvania Glaciation, First Phase,* published in 1917.

In these studies he noted that there are very few Canadian rocks or rocks of distant derivation in this district, but clear evidence was found of the transportation of certain local rocks to points beyond the limits of their outcrop in directions consistent with glacial movement and out of harmony with the flow of streams in their present drainage courses.

To what degree these glacial deposits owe their scantiness to original meager deposition, and to what degree to a long period of erosion, is a matter difficult to determine. It is, however, probable that in this early glaciation, as in the Illinoian, a considerable part of the district received only a thin cover of drift. Much of the district is so rugged that the ice could scarcely have had free movement. The height of mountains above the bordering lowlands was probably about the same as today in this district. It seems not improbable that the ice in the lowlands was in some cases so checked in its movement by ridges athwart its path as to become practically stagnant, or to have moved only in the upper part that stood above the level of the barrier. This part may have had sufficient freedom of movement to produce the observed planing and removal of the weathered part of outcrops.

Whether this district outside the Illinoian drift border was glaciated more than once is at present undetermined. The natural inference from the scantiness of the deposits is that a single glaciation would have been fully adequate to do all the work or produce all the effects here exhibited. There is, however, a suggestion of twofold glaciation in outlying gravel deposits in New Jersey and eastern Pennsylvania. The Pensauken and Bridgeton gravels of New Jersey both carry rocks that seem to be of glacial derivation, and both seem to be much older than the Illinoian drift. The Pensauken is separated from the Bridgeton by a wide interval of erosion, apparently as great as that between the Kansan and Nebraskan drifts of the Mississippi basin. The Pensauken may thus fall in the Kansan stage, and the Bridgeton in the Nebraskan. This matter is more fully discussed elsewhere in this report, as well as in what follows. (See pages 88-90).

Extent of glaciation. There are several elements of uncertainty as to the extent of this early glaciation. The scantiness of the deposits is generally such as to make it impracticable to determine the limits with the precision that is feasible with the later drifts. The deposits also are in some cases of questionable nature, lacking in common characteristics of glacial material, such as striated pebbles, or rocks foreign to the locality. Then there is uncertainty as to the height to which prominent ridges that lie within the drift border were covered by the ice sheet.

The drift limit of Williams from Lock Haven northwestward as given in his *Pennsylvania Glaciation, First Phase*, published in 1917, is much farther west than that given in his earlier publications. The present writer has examined features cited by Williams in support of this extension of glaciation to the wider limit, northwest of Lock Haven, but has not found them such as to clearly indicate glaciation. There seems good reason, from the presence of erratics and deposits of till, for extending the glaciation westward from the West Branch into the recesses between the mountains, from Shamokin Mountain northward to Bald Eagle Mountain, in Union and Lycoming counties. But it seems less clearly established that the ice covered these mountains to the extent set forth by Williams. It seems doubtful if glaciation extended west of Pine Creek in the part of the Allegheny plateau south of Slate Run. But it may have extended up the West Branch to Lock Haven in the district south of the Allegheny plateau. There may also have been glaciation west of the Wisconsin boundary in southwestern Tioga County and adjacent parts of Lycoming and Potter counties. In the district east of the Susquehanna, as far as the headwaters of Schuylkill River, patches of till are present at frequent intervals about to the limits given by Williams. But the evidence of glaciation on the flanks of Blue Mountain from Schuylkill River eastward seems to be very indefinite, outside the limits of the Illinoian drift, and the writer is disposed to question its extent to the limits given by Williams.

Drift in the vicinity of Hazleton. A tableland south of Hazleton on the divide between the Susquehanna and Lehigh drainage, with an altitude of 1,700 to 1,800 feet, carries a thin sheet of drift, usually 10 feet or less, in which stones of all sizes and degrees of angularity are imbedded in a clayey matrix. It is well exposed by the extensive coal mining in the vicinity of Audenried and McAdoo, and seems to have been preserved in a nearly continuous coating. The coarse fragments are very largely from local formations, and the small pebbles are from the conglomerate ledges that are exposed on the crests of neighboring ridges. There is little or no material of Canadian derivation. Striated rocks are also very rare. But the deposit seems to have been worked over by the ice sheet sufficiently to give a mixture of various kinds of rocks such as is characteristic of till.

A similar deposit is found in the south part of Freeland on land to still greater altitude, the highest part being about 1,900 feet. The matrix is clayey and the rocks a mixture of various kinds. The ridges all around this area lack this coating, even when composed of shale, as is the case in the west edge of Freeland, on land 2,000 feet above sea level.

In the valley of Black Creek, between Freeland and Hazleton, at an altitude of about 1,500 feet, there are glacial deposits from 20 to 60 feet in thickness, well exposed by coal mining for several miles, from Eckley down to Harleigh. At a pit in Harleigh, west of the Interurban Electric Railroad, a gravel deposit is exposed beneath 20 to 25 feet of red clayey till, carrying striated pebbles. Till is found in smaller amount farther down the valley past Tomhickon. It is found also in a pass southwest of Tomhickon, between Black Creek and Catawissa Creek drainage, at an altitude of 1,450 feet.

GLACIAL FEATURES ON BORDER OF SCHUYLKILL AND SUSQUEHANNA DRAINAGE

The ice appears to have crossed over the headwaters of Catawissa and Mahanoy creeks of the Susquehanna drainage in Schuylkill County and invaded the headwaters of Schuylkill and Little Schuylkill rivers. The trend of the ridges and valleys in this county that fall within the Susquehanna drainage is not far from east to west but it is doubtful if the ice flow followed their trend, except in the initial stages. At the culmination of the glaciation it may have taken a southward course across them. If the valleys had become filled to a depth of 400 to 500 feet by ice the ridges would have had but slight relief above its surface and might easily have been crossed as the ice became thicker. A filling of 500 feet in Mahanoy Valley west of Mahanoy City would have given a southward flow across a pass near Morea into Mill Creek, a tributary of Schuylkill River. This pass is below 1,540 feet, and Mahanoy Valley north of it is about 1,140 feet. Williams determined that there was a southward movement into this part of Mill Creek valley, as the coal was carried in that direction from its outcrop.

It was here at the pit in the Mammoth coal that Williams observed a striking exhibition of glacial planing, a view of which is given in Figure 25. The weathered coal was removed and carried southward in the thin sheet of till shown at the border of the pit. The coal as now exposed in the pit is solid enough for the market clear to the surface. At the time of the present writer's visit in 1927 the coal surface had been exposed for about a quarter of a mile and was planed off the entire length of the exposure. The drift cover is from 8 to 15 feet thick. In places it is partially assorted. It includes a variety of rocks, showing that it was brought in to some extent from outside the immediate outcrops in the Mill Creek drainage. A careful study of the kinds of rock might be of significance in determining the course of ice movement.

The surface of the Mammoth coal bed where this glacial planing is exhibited is about 1,500 feet above sea level. To how much greater

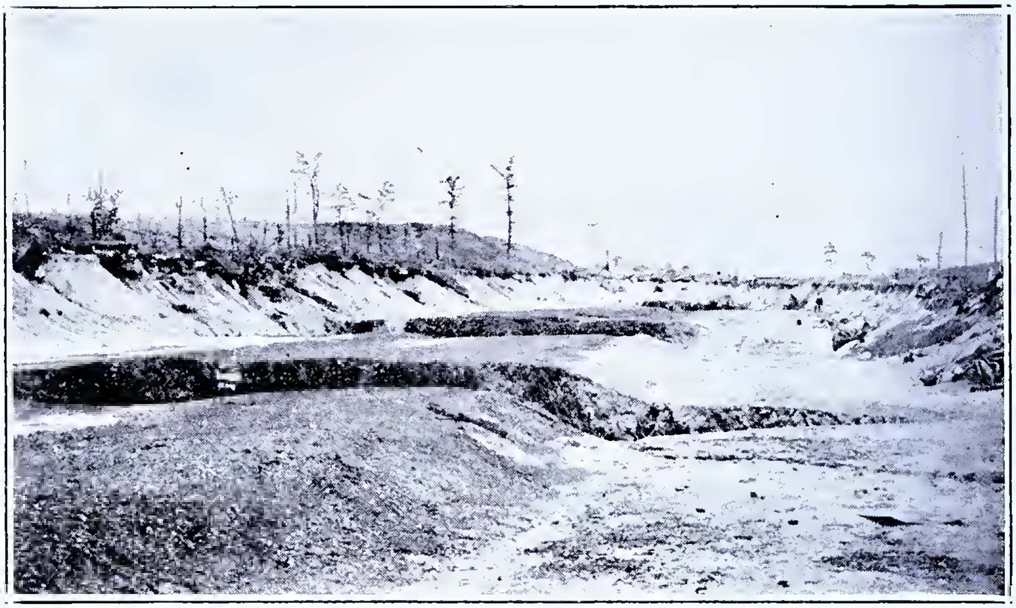

Figure 25. Mammoth coal bed at Morea planed off by ice and overlain by early glacial till. Photo by E. H. Williams, Jr.

height the ice reached in that vicinity was not clearly determined. It was found, however, that a pebbly loam is widely preserved on ridges east of Morea up to nearly 1,700 feet. In places this loam carries red rock material where the underlying rock is a quartz conglomerate, thus indicating transportation consistent with glacial action. But striated pebbles were not noted in these places, and it is felt that more careful study should be given the deposits to determine to what extent, if any, they are glacial.

In the vicinity of the divide between the Susquehanna and Schuylkill drainage in and near Frackville there are deposits of red pebbly clay that are suspected to be of glacial derivation. Along the railroad in the south part of Frackville these deposits rest on conglomerate. The thickest deposit is not over 6 feet. They occupy slight depressions on the surface of the conglomerate. The altitude is about 1,500 feet. These deposits appear to be at or very near the southern limit of the drift. They are on the south bluff of Mahanoy Creek about 350 feet above the valley bottom. North of the creek, both east and south of Shenandoah, patches of clayey material were noted that carry a variety of rock apparently gathered by the ice from points more or less separated in their outcrop, and deposited over the conglomerate ledges.

GLACIAL FEATURES EAST OF SUSQUEHANNA RIVER

At Locust Summit, on the divide between Mahanoy and Shamokin drainage, at an altitude of 1,240 feet a railroad cut exposes till with a depth of 10 to 15 feet. The pebbles, which range in size up to about one foot in diameter, show a deep weathered rind, and a few were found which exhibit glacial planing and striation. A variety of rocks is present.

The course taken by the ice sheet to reach Locust Summit can perhaps be determined by a careful study of the rocks in the till by a person well versed in the stratigraphy of the region. To reach here from the north the ice would have to cross several ridges, Little Mountain, Big Mountain, and Locust Mountain, with crests 1,600 to over 1,800 feet. To reach here from the east it would have found narrow passages between the ridges. It seems not unlikely that the ice had sufficient thickness to cover these ridges at its culminating stage. Indeed, there are deposits on Big Mountain near Montana which may be of glacial derivation. A deposit of pebbly clay several feet thick covers a gently undulating part of the mountain crest at 1,680 to 1,740 feet in and north of the village. The writer did not find striated stones in this clay, but the variety of rocks included in it appears to be greater than would be found in a residuary clay. This clayey deposit is on the divide between Shamokin Creek and Catawissa Creek. Ice in the Catawissa drainage basin would have had an open path up to this pass in a southwestward course. Having surmounted this pass it would have had but little obstruction in crossing Locust Mountain and reaching Locust Summit to lay down the deposit of till noted above.

The valley of Shamokin Creek in the vicinity of Mount Carmel, and a lowland between the creek and the south base of Big Mountain, drained by Quaker Run, contain thin deposits of stony clay that seem to be in part at least of glacial derivation. In an exposure near the western limits of Kulpmont this clay overlies a pebbly bed thus making clear that it is not a residuary product at that place. It seems probable that a considerable part of the deposit in this lowland had been developed either as residuary or as alluvial material before the ice came in, and that it was merely worked over and transported a short distance by the ice sheet.

After passing through gaps in Big Mountain and Little Mountain north of the city of Shamokin, Shamokin Creek enters a lower country in which patches of till are not infrequent. They were noted along the highway between Paxinos and Stonington, and in the vicinity of Seven Points. The pebbles show a deep weathered rind and etched surface, strikingly greater than is exhibited by the pebbles in the Illinoian drift in the district to the north, between Shamokin Creek and Susquehanna River. The till also is deeply weathered throughout in this older drift. It lacks the hummocks of constructional type found on the neighboring part of the Illinoian drift. in the headwaters of Little Roaring Creek. It was in this district that the writer first became impressed with the striking difference in the degree of weathering of the Illinoian and the pre-Illinoian drift.

GLACIAL FEATURES ON BORDERS OF WEST BRANCH

As already indicated, patches of till and scattered erratics are present on both sides of the West Branch of Susquehanna River in the section between Northumberland and Watsontown that was not covered at the Illinoian stage. The till is deeply weathered, and is found in passes between drainage lines, or in narrow strips on the divides, in places where erosion has been at a minimum. It thus seems to be a remnant of a till sheet that may originally have covered a considerable part of the surface. Northwest of West Milton near the Robin School till was noted at an altitude of fully 700 feet, and boulders and cobble are present up to still higher altitude near the east end of Nittany Mountain. But as a rule the till patches are below 700 feet. In the northwest part of the Sunbury quadrangle they are commonly found at an altitude of less than 600 feet. In the eastern part of the Milton quadrangle the till patches are at similar low attitude, but boulders and cobble extend to about 800 feet near the south base of Muncy Hills. On the prominent hills west of the Susquehanna River below Montgomery, boulders and cobble are present about to the highest points (Figure 9). Boulders were noted at about 900 feet both on the north and south slope, and cobblestones to 980 feet on the crest. At the west end till is present half a mile northeast of the Stone Church to about 740 feet. This appears to be above the level of the Illinoian till of the adjacent district north of the hills. The White Deer Valley west and south of these hills carries a thin coating of glacial material, with some till as well as boulders and cobble. As indicated in the discussion of the Illinoian drift, there is uncertainty as to whether this valley was occupied by the Illinoian ice sheet.

It seems probable that the pre-Illinoian glaciation in this part of West Branch of Susquehanna River below Bald Eagle Mountain came mainly from a southward movement into the valley over the Allegheny Front and through the valleys of Muncy and Loyalsock creeks. But the valley may also have been invaded by a westward movement through the lowland south of the Muncy Hills. Detailed study of the kinds of rock contained in the drift may show to what extent each movement was operative.

GLACIAL FEATURES WEST OF SUSQUEHANNA RIVER

The ice movement into the headwaters of Middle Creek in the lowland between Shade Mountain and Jacks Mountain as mapped by Williams seems to have left very little drift, for the writer was able to find only an occasional rock that seems likely to have had glacial transportation. A few small boulders of indurated sandstone or of quartzite were noted in areas of shale, but the great preponderance of loose rock material is of native rock. In Middle Creek Valley above Beavertown, along the base of Shade Mountain, deposits of stony clay in which the stones are more or less rounded form a nearly continuous coating several feet thick. This material seems likely to have been washed into this lowland by stream action on the slope of the mountain, and to have been affected but little by glacial action. At the divide at the head of the creek about two miles west of McClure there is a prominent accumulation of very stony clay that runs like a transverse moraine across the valley and a short distance up the slope on the side opposite the mountain. Its altitude is about 800 feet, as shown by the contours of the Mifflintown quadrangle (Figure 26). This is at Rager Summit on the Lewistown Branch of the Pennsylvania Railroad. The railway cut here, 12 feet deep, is entirely in a stony clay. The deposit seems to extend much deeper. The map indicates a descent of 60 feet within one-third of a mile both east and west from the summit, and no rock is exposed in the valley floor in this interval. An examination of several hundred specimens failed to show striated stones in this deposit, but most of the stones were too much weathered and exfoliated to retain light striation. The writer is disposed to refer this deposit tentatively to glacial action. It seems to extend too far away from Shade Mountain to be due to a landslide, and runs up on the north slope to a higher altitude than seems natural for a

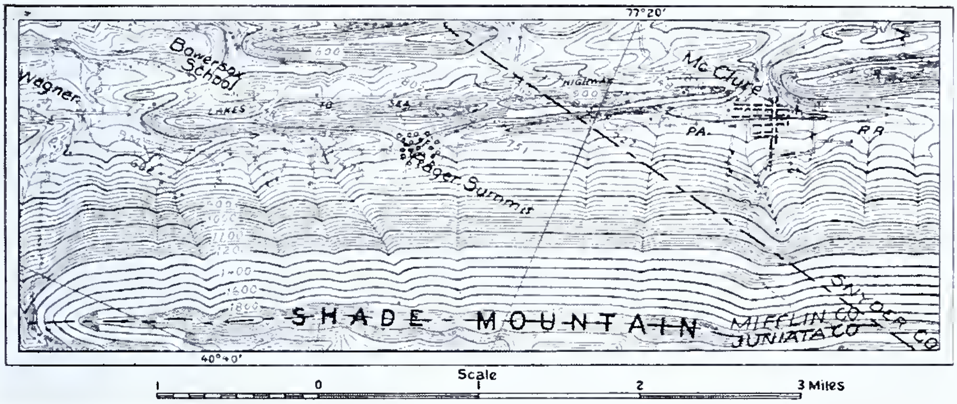

Figure 26. Topographic map showing glacial deposits near McClure in a pass at divide between Susquehanna and Juniata drainage.

deposit of that sort. West of this summit the valley has a more stony, or less clayey deposit than to the east, a feature that may be due to westward drainage from the end of an ice lobe terminating at the summit in the valley. The descent down this westward drainage to Jacks Creek at Wagner is 250 feet in two miles.

It seems probable that glaciation extended well up on the slopes of Jacks Mountain near Millmont, and protruded into the recess between Jacks Mountain and Paddy Mountain as far as Weikert. In this recess boulders and smaller waterworn sandstones are scattered over the shale lowland and some of the bowlders appear to show glacial planing though they do not carry distinct striae.

Glaciation may have extended to considerable height on the northeast end of Paddy Mountain and well up on the slopes of White Deer Ridge and Bald Eagle Mountain near their eastern ends.

Glacial deposits, including patches of till, are present in the district between the Allegheny Front and West Branch of Susquehanna River from Lycoming Creek westward past Larrys Creek and up to an altitude of over 1100 feet above sea level. They are most abundant near the base of the mountain and become scanty at a distance of two miles from it. This seems to indicate that the stony material had been carried into the lower district from the Allegheny Mountain prior to the glacial advance, and was then worked over by the ice sheet and deposited as till. The drift was in this way made to veneer the slopes and was left in positions beyond the range of the original mountain wash.

From Pine Creek Valley westward to where the West Branch emerges from the Allegheny Mountains near Lock Haven there are scattered cobbles in cols and on flat areas south of the mountains up to an altitude of over 1000 feet. The largest stones seen are 5 or 6 inches in diameter, but the majority are less than 3 inches. They are mainly sandstone, but include a few quartzites. These pebbles all show very deep weathering and seem to date back to early Pleistocene time. Whether they were directly deposited by the ice seems open to question. If ponding to the level of the Dix summit was produced by the blocking of drainage down the West Branch these pebbles may have been rafted on ice in ponded waters to points outside the limits of the ice sheet.

In Nippenose Valley south of Bald Eagle Mountain the limestone formation has a coating of rubble which seems to have been washed in from the mountains that surround it. It is doubtful if the ice came into this valley through the gap along Antis or Nippenose Creek. The writer, however, found a clay deposit carrying rounded stones in a recent sink hole that opened in 1928 a mile west of Oval. The deposit is about 6 feet thick and rests upon the limestone. This sink is on the highest land in the midst of the valley, being above 840 feet, as shown in the topographic map of the Williamsport quadrangle. It thus seems to be in a situation unfavorable for receiving rolled material from the mountains. But in the course of ages places in such valleys that once were the lowest ground may become less eroded or lowered less by solution than surrounding land and thus come to stand in relief above it.

The features cited by Williams in his "Pennsylvania Glaciation, First Phase" as evidence of glaciation in the district northwest from Lock Haven do not, in the present writer's opinion, support this interpretation. One of the features taken as evidence of glaciation is the presence of rolled material near the headwaters of certain streams. Thus on West Creek he considers the gravel "too well rolled for a carriage of 5 miles from the source." In a cut on the Pennsylvania Railroad east of Medix Run station the gravel and cobble and bowlders of a terrace of Bennett Branch standing about 75 feet above the stream are interpreted by Williams to be a moraine. An area of about 40 acres of flat terrace is here preserved at the place where Medix Run came into Bennett Branch. This deposit as well as similar deposits along Bennett Branch above and below Medix Run seem to be ordinary fluvial deposits, in no way dependent upon glaciation. Gravel in headwaters of the Clarion at St. Marys, Wilcox, and near Clermont is also cited by Williams as of glacial origin, but there seems no reason for bringing in glacial action to account for its presence. Williams also cited the swampiness of parts of the plateau at the headwaters of the Clarion as an evidence of glaciation. In most cases, if not in all, there are swampy conditions where a resistant rock caps the plateau and prevents trenching by the small headwater streams. Katrine Pond swamp, cited as a conspicuous case, is not on the general level of the plateau at 2300 feet, but is in the head of Five Mile Run in a valley 100 to 150 feet below the plateau. The stream here is unable to deepen its valley and so has developed a swampy condition.

PRE-ILLINOIAN GLACIAL DRAINAGE

Glacial Lake Lesley. The ice sheet extended beyond the lower course of West Branch of the Susquehanna River so far in this early stage of glaciation that it seems improbable that the drainage from it at the culminating stage could have been along or close to the valley as it probably was at the Illinoian stage. Williams assumed that ponding occurred in Bald Eagle Valley to sufficient height to give a discharge across a col at Dix into the Juniata drainage, the height being slightly above 1100 feet. To this body of water he gave the name "Glacial Lake Lesley."[1] He also assumed that a vigorous drainage was carried into the Juniata Valley over the col west of McClure at the head of Middle Creek. He gave this col an altitude of only 650 feet, but the Mifflintown topographic map shows it to be nearly 800 feet (Figure 26). At this place he inferred that ponding occurred after the ice border began to shrink back from its culminating position at the col.

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[1] Am. Jour. Sci., 3d ser., vol. 49, 1895, pp. 183-185. For map of the lake area, see Proc. Wyoming (Pa.) Hist. and Geol. Soc., vol. 7, 1902, p. 4. The lake is also discussed in *Pennsylvania Glaciation, First Phase*, 1917, pp. 66-70.

The writer made an examination of Bald Eagle Valley in 1927 with the expectation of finding features that would show whether there was vigorous glacial drainage into the Juniata Valley from the hypothetical Glacial Lake Lesley. But instead of finding features that would throw light on this question, it was found that the present western tributaries of the stream that drains the part of the valley south of the divide have brought in the deposits that are open to inspection, and concealed any deposits that might be referable to glacial drainage. It was found that the gravel deposits from Bald Eagle Station down to Tyrone were brought into the valley through Big Fill Run. Those at Vail and Tyrone which have been interpreted by Williams as the product of drainage from Lake Lesley were brought in by this western tributary, and have no relation to the hypothetical lake. So great a volume of gravel and coarser material was brought in through Big Fill Run that it produced a barrier in the valley about as high as the Dix summit, 3 miles above the mouth of this tributary (Figure 27). A

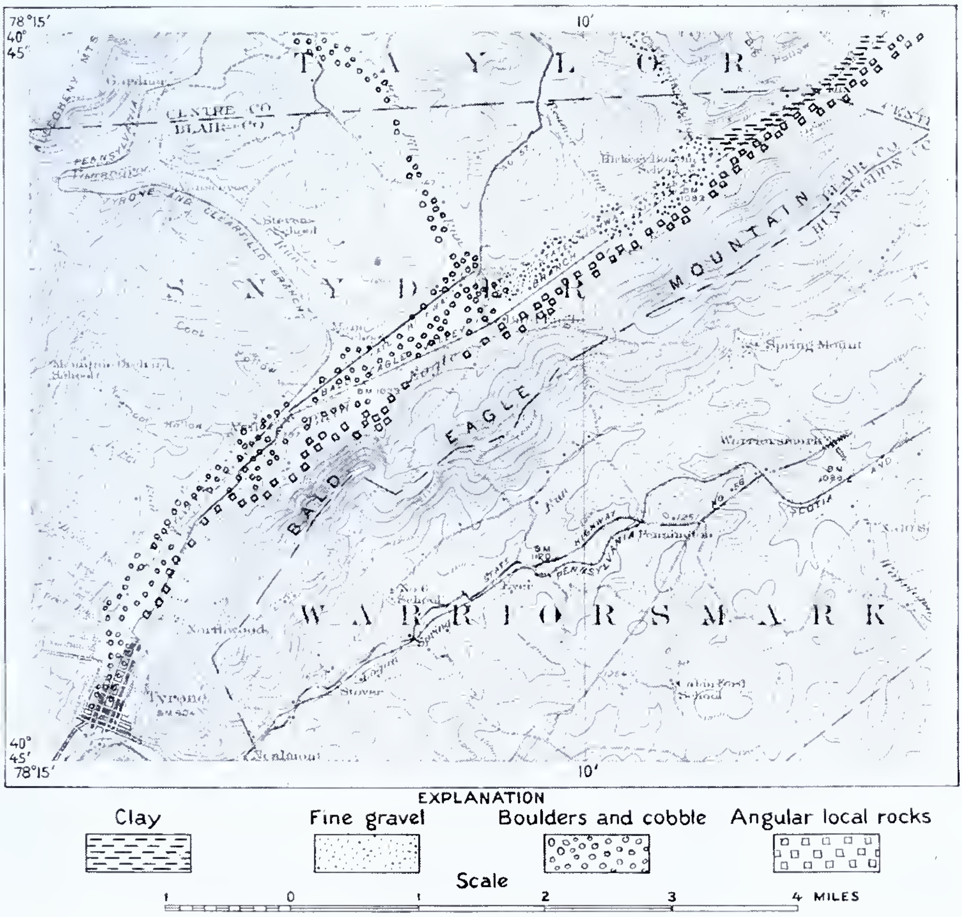

Figure 27. Topographic map showing deposits in Bald Eagle Valley northeast of Tyrone.

less conspicuous deposit of cobbly material was brought in through California Hollow, a western tributary entering the valley only a mile below the Dix summit. From the mouth of this tributary up to and a little beyond the summit there is a clay deposit with a depth of several feet, as exposed in ditches along the railroad. This seems to have been washed in from the shale bluffs along the west side of the valley. On the east slope there is rubble from Bald Eagle Mountain. The local deposits thus are of sufficient amount to conceal any deposits that were brought in so long ago as the time when the West Branch of the Susquehanna was most extensively blocked by the ice sheet. It appears that "Glacial Lake Lesley" is merely a hypothetical conception, difficult either to prove or disprove. Any shore lines that it may have formed are likely to have been too faint to withstand the changes that the slopes have experienced in so long a period of erosion. The narrowness of the pass at Dix, about one-eighth of a mile, is such as to indicate that any glacial drainage across it must have had rather small volume. The same is true of the pass west of McClure, at the head of Middle Creek (Figure 26). It thus appears probable that the main drainage of this part of the ice sheet in the pre-Illinoian stage was down the Susquehanna from near the mouth of Middle Creek, as it was in the Illinoian stage.

HIGH-LEVEL GRAVEL IN SUSQUEHANNA VALLEY BELOW SELINSGROVE

Along the Susquehanna Valley south of the limits of glaciation waterworn pebbles and cobblestones have been noted at altitudes considerably higher than the gravel train connected with the Illinoian glaciation. At several places above Harrisburg they have been found as high as 600 feet above sea level, or more than 200 feet above the present stream, and they may extend still higher. They are present at various levels down nearly to that of the Illinoian terrace. They are strewn over gentle slopes as well as over surfaces that are nearly level. They do not seem to form so definite a fluvial plane as the gravels of Illinoian age. There are better preserved benches near the lower level of these pebbles than higher up, but even there the benches are preserved for only short distances. The most conspicuous bench above Harrisburg is in the red shale area back of Dauphin. A considerable part of its surface is between 480 and 540 feet above sea level. It also is thickly strewn with pebbles.

Opposite Harrisburg and below that city extensive limestone lowlands are crossed by the river, but these seem to have derived their low altitude as a result of solution rather than river action. Pebbles are inconspicuous on them at levels above the Illinoian gravel. In the gorge below Columbia sections of old fluvial planes, carrying pebbles derived from far up the river, are found up to a level of about 540 feet near McCalls Ferry. It seems clear therefore that the river has had its present course to Chesapeake Bay from a time far enough back to include all the pebbly deposits noted along the valley between Harrisburg and the drift border.

It remains to consider to what extent these deposits are connected with the early Pleistocene glaciation. The pebbles are very largely of quartzite from formations which are crossed by the river, red Medina quartzite pebbles being conspicuous in the gorge below Columbia as well as in the part above Harrisburg. Quartz pebbles also are common, and there are occasional trap pebbles, derived from dikes exposed near the river.

The pebbles are generally 3 inches or less in diameter, and but few exceed 6 inches. One of the largest stones noted, and one which may have considerable significance in determining the relation of these deposits to the early glaciation, is a cobble of granite gneiss, 9 by 7 by 5 inches in diameter, found on the bench back of Dauphin, at an altitude of 500 feet (Fig. 28). It seems to have been reduced somewhat by exfoliation, and is so decayed that it can be crumbled in the hand. Inasmuch as there are no outcrops of gneiss in the part of the Susquehanna drainage basin above Dauphin and all rocks of this class were brought in by glacial action from districts farther north, this rock, if *in situ* where found, gives clear evidence that the pebbly deposits up to that altitude are connected with the early or pre-Illinoian glaciation. The locality is about 30 miles down the valley from the border of the drift. It seems highly improbable that a rock so deeply weathered would have been brought here by man. It harmonizes well in degree of weathering with pebbles of other kinds found in the same locality. So there seems to be no reason for questioning its being *in situ*. The case will be strengthened if other specimens are found that are clearly referable to glacial agencies. It also will be important to search for them at higher altitudes. This specimen was found at the general level of the red shale bench so well preserved in the vicinity of Dauphin, and which has the appearance of an old fluvial plane. It is a matter of importance to determine whether this bench correlates with the earliest glacial stage, or was developed later. Later studies show that most of the pebbles on the bench back of Dauphin and on the slopes for 100 feet above it have been derived from the local Mauch Chunk

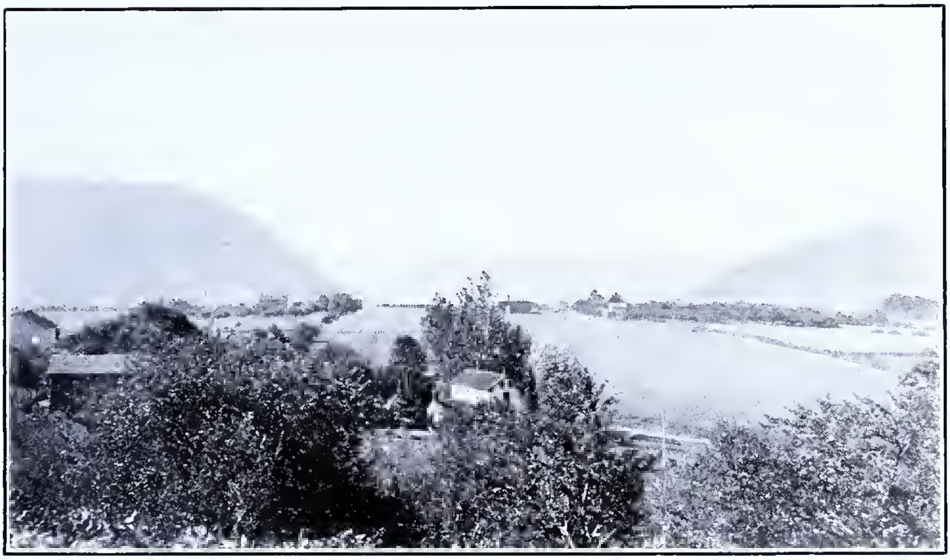

Figure 28. Terrace back of Dauphin which carries pebbles at about 500 feet above sea level. Photo by Geo. H. Ashley.

conglomerate bedrock. A few pebbles appear to be river pebbles of later age.

On the same bench that carried the gneiss cobble and about 3 miles west a remarkable number of pebbles of red quartzite occur. In some the amount of iron is so great as to give the appearance of jaspilite. The finer grained rocks seem to carry more iron than the coarser grained. They also seem to be unlike the common red quartzites of the region. A specimen of one of the finest grained rocks was submitted to Prof. Walter F. Hunt of the Mineralogy Department of the University of Michigan, for the purpose of getting a slide for microscopic study. An inspection of the slide under a microscope showed the following characteristics as reported by Professor Hunt:

> Fine textured ferruginous quartzite.
>
> The main constituent is crystalline quartz with very irregular outlines. The grains interlock, producing a mosaic structure. There is no distinction of original grains and cementing material. Through the section are observed veinlets of quartz consisting of larger grains, but with the same interlocking character. These larger grains show a shadowy extinction indicative of strain (metamorphism) to which the rock was subjected. Hematite is very abundant, coloring the rock section red. It occurs in two forms—translucent hexagonal plates and as opaque earthy masses. The hematite is irregularly distributed throughout the slide in streaks and poorly defined circular and elliptical patches. Black opaque magnetite is also present, which seems, in some instances at least, to be responsible for some of the hematite, as one form of iron oxide grades into the other.
>
> It is quite possible that this rock was a chert before the metamorphism, but these geological processes have recrystallized and enlarged the grains so that I think, in the present form, it might be more appropriately called a fine textured ferruginous quartzite.

RELATION OF GLACIAL DEPOSITS TO THE SUNDERLAND FORMATION

A few remarks may be in place here concerning the probable correlation of the early glacial deposits with a formation of the Coastal Plain. As already indicated (p. 33), the Illinoian terrace of the Susquehanna Valley appears to find its closest equivalent in the Wicomico formation of the Coastal Plain series. This being the case, the next higher formation of the Coastal Plain, the Sunderland, would seem to be the natural one to correlate with the pre-Illinoian glaciation. It is regarded by those most familiar with it as a Quaternary formation, which in itself suggests this correlation. The writer is personally familiar only with the parts of the Sunderland formation near the head of Chesapeake Bay, and in the vicinity of Washington, D. C. The degree of erosion displayed in these places seems fully as great as that displayed by the old drift of eastern Pennsylvania and New Jersey, and the Kansan drift of the Mississippi basin. It is markedly greater than that of the Illinoian and the Wicomico.

PRE-PLEISTOCENE DEPOSITS

There are pebbly deposits within the Susquehanna drainage basin which are apparently far older than the earliest stage of Pleistocene glaciation. A conspicuous instance is found on the border of the Juniata Valley north of Huntingdon (Figure 22). The pebbles there are on a divide between the river and an eastern tributary that enters at Huntingdon. Their deposition seems to have antedated the cutting of a narrow valley 400 feet deep in which the river now flows. They were noted up to an altitude of fully 1060 feet. They are well rounded pebbles of sandstone and quartzite from 2 to 5 inches in diameter. Charles Butts, of the U. S. Geological Survey, found pebbles at a similar height in neighboring parts of the Juniata drainage basin, and has considered them of late Tertiary age.[1]

A pebbly deposit probably of much greater age than that near Huntingdon occurs in York County on the southwest side of Susquehanna River nearly opposite Marietta at an altitude about 750 feet. This high deposit carries bowlders nearly a foot in diameter as well as smaller stones, all well rounded, and apparently all of quartz. The altitude of the deposit is about 500 feet above Susquehanna River, and more than 250 feet above broad lowlands in that part of the State. The deposit is on a narrow bench on the north slope of a range of hills with points up to 1050 feet above sea level that runs from York northeastward to the bend of the river at Chickies, just below Marietta. The time required to effect so great a reduction in the bordering lowlands as is found in this part of Pennsylvania is evidently much greater than is involved in the Glacial epoch and probably embraces a considerable part, if not all of the Tertiary period.

Pebbles are scattered widely over the lowlands east of the Susquehanna Valley between Washingtonboro and Lancaster, some having been found at points 8 miles from the river, or only 3 miles from Lancaster. Among the pebbles are red quartzites that are thought to be from Medina or perhaps from Clinton formations farther up the Susquehanna. They seem to indicate a rather wide wandering of the

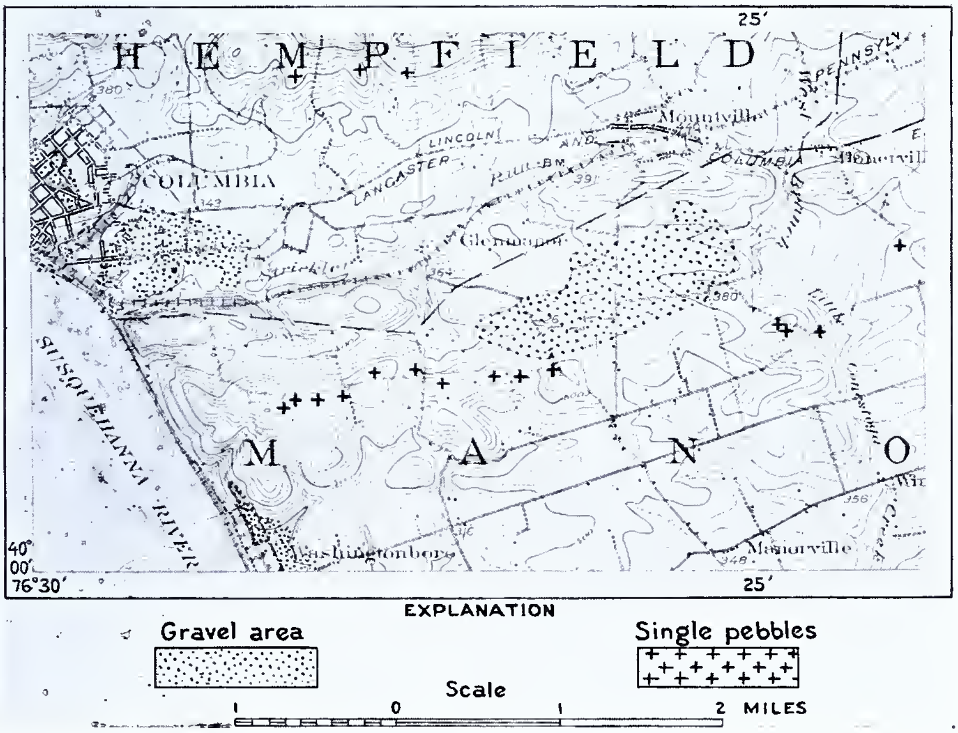

Figure 29. Topographic map showing Illinoian gravel near Columbia and pre-Pleistocene gravel near Mountville.

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[1] Personal communication.

river over these lowlands at a time when it was flowing at a level about 200 feet above its present bed. Those farthest from the river are on ground 400 to 420 feet above sea level. On the eastern slope of a group of hills back of Washingtonboro scattered quartzite pebbles were found up to about 560 feet above sea level. About 2 miles northeast of Columbia waterworn pebbles of local rocks occur on a bench on the south slope of the hills near Ironville at about 520 feet, or 100 feet above a lowland to the south drained by Strickler Run, and 180 feet above the Illinoian gravel at Columbia (Figure 29). It seems probable that the pebbles at the higher levels antedate the Glacial epoch, and perhaps those down to 400 feet do also.

The most conspicuous deposit of pebbles in this district is on the divide between Strickler Run and the West Branch of Little Conestoga Creek south of Mountville (Figure 29). The pebbles are concentrated in swales at about 420 to 440 feet, but are scattered over the slopes up to nearly 500 feet. They are mainly of vein quartz, which outcrops in the area they cover. There are some bowlder size 1 to 2 feet in diameter, that seem to show considerable water wear, as if they had been rolled a long distance, yet it seems more natural that they should have been derived from the local outcrops. Where concentrated the pebbly deposits are several feet deep, so that gravel pits have been opened in them. They have surprisingly slight extent down the slopes toward drainage lines to the east and west, and the limits of the deposit are so definite as to be mapable to within a few rods. The area covered is about a square mile. This deposit also seems likely to antedate the Glacial epoch.

NOTE. After this report was prepared and setup, Professor Leverett saw a copy of the Warrensville topographic map which convinced him that his mapping of the Wisconsin border shown on Plate I, was not right between Loyalsock Creek and Wallis Run. Mr. Forrest T. Moyer of the Survey, therefore, examined that area and reports his results as follows:

Along the south side of Wallis and King runs the Wisconsin debris is traced up the slopes of Cove and Jacoby mountains to an elevation between 1,200 and 1,300 feet. Just east of Wallis Run Church the fluvioglacial plain is at 800 to 820 feet and the debris of the same age is present up the hill slope to an elevation of 1,200 feet. There are indications that a tongue of Wisconsin ice extended south along Wallis Run to half a mile south of the junction with Murray Run. At this point the hill slopes descend almost directly to the creek level, forming a narrow steep gap. South of the gap no debris is found on the hill slopes above the outwash plain.

Southwest of Proctor on the slopes of Cove Mountain the Wisconsin debris attains an elevation of 1,300 feet. In the vicinity of Barbours where Plunketts Creek joins Loyalsock Creek, the upper limit of debris is at 1,200 feet. From this point southwest along Loyalsock Creek, observable data are scarce, but pointing to a tongue of Wisconsin ice extending at least 2 miles down the stream valley to Smiths Knob. Possibly the ice may have extended as far downstream as the junction of Dry Run with Loyalsock Creek, where a narrow steep gap occurs. The steep and heavily wooded valley sides prevent a clear interpretation of the southwest extent of this tongue of the glacier.

The more or less flat tops of Cove and Jacoby mountains attain elevations from 1,480 to 2,000 feet. Glacial debris of much older appearance and character than Wisconsin material was found on all the flat tops. This material is probably of Illinoian age.

One mile southwest of Barbours a pronounced flat occurs on the steep hill slope of Cove Mountain. The flat has an elevation of 1,400 to 1,440 feet and shows glacial debris of the Illinoian type.

PRE-WISCONSIN DRIFTS OF EASTERN PENNSYLVANIA AND NEW JERSEY

ILLINOIAN DRIFT SOUTH OF BLUE (KITTATINNY) MOUNTAIN

DISTRIBUTION

The Illinoian drift south of Blue (Kittatinny) Mountain in Pennsylvania covers nearly the entire area of the limestone and slate formations between Blue Mountain and South Mountain from the Delaware Valley westward to a line a few miles beyond the southward-flowing part of Lehigh River. It also seems to be represented in deposits west of Riegelsville on the west side of Delaware River. Near Bethlehem, it extends several miles south of Lehigh River into a lowland drained by Saucon Creek (Fig. 30), but elsewhere, from Easton up to Allentown, its border is very near the river. The border turns away from South Mountain at Emaus and runs northwestward past East Texas to Chapman (Fig. 31). It then runs northward past Siegersville about to Schnecksville. There is some uncertainty as to its further course, for the surface here is more hilly, and the deposits more scanty than in the lower country to the south. Some hills rise above 900 feet, and seem to be free from erratics. The depressions among them carry very little till, but contain many stones, a few of which are glaciated. Some of the stones seem to have been rounded by water action, though many

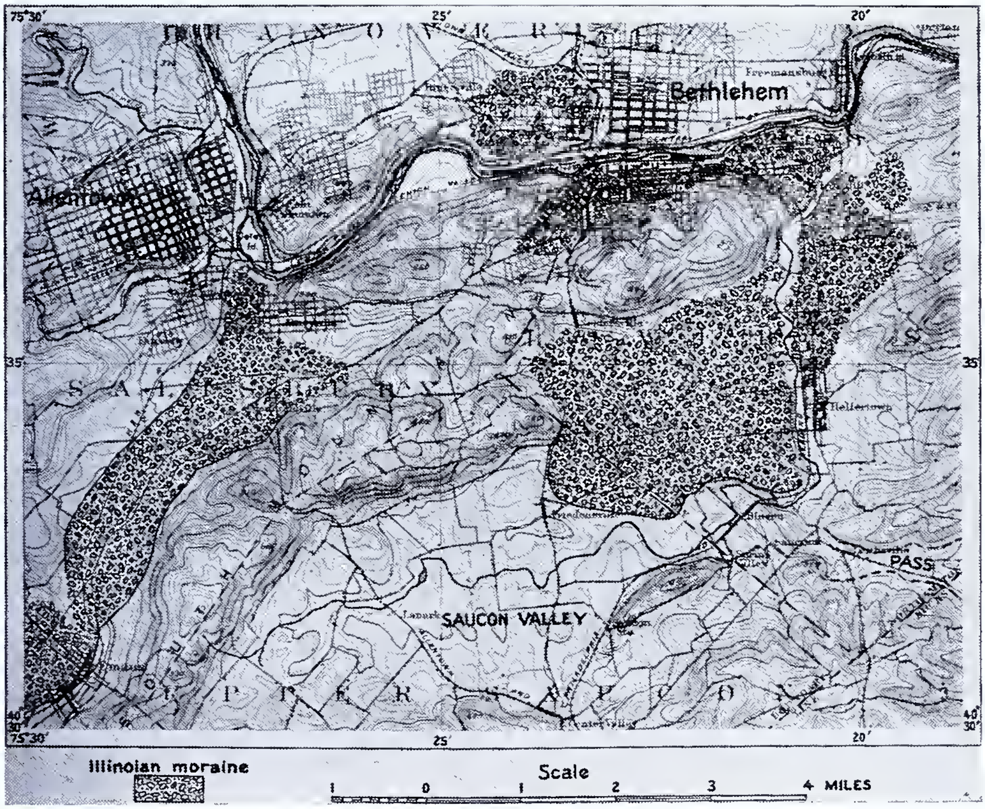

Figure 30. Topographic map of part of Allentown quadrangle showing Illinoian moraines near Bethlehem.

of the sandstones may have been rounded by exfoliation. These stones are present in notable amount as far out as a line running from Schnecksville past Pleasant Corner about to New Tripoli. Williams reported that some of the stones in this region were brought over Blue Mountain, and stated that the county bridge over Jordan Creek near Pleasant Corner has in its foundation stones of such derivation.[1] There is a strip of somewhat lower land between these hills and Blue Moun-

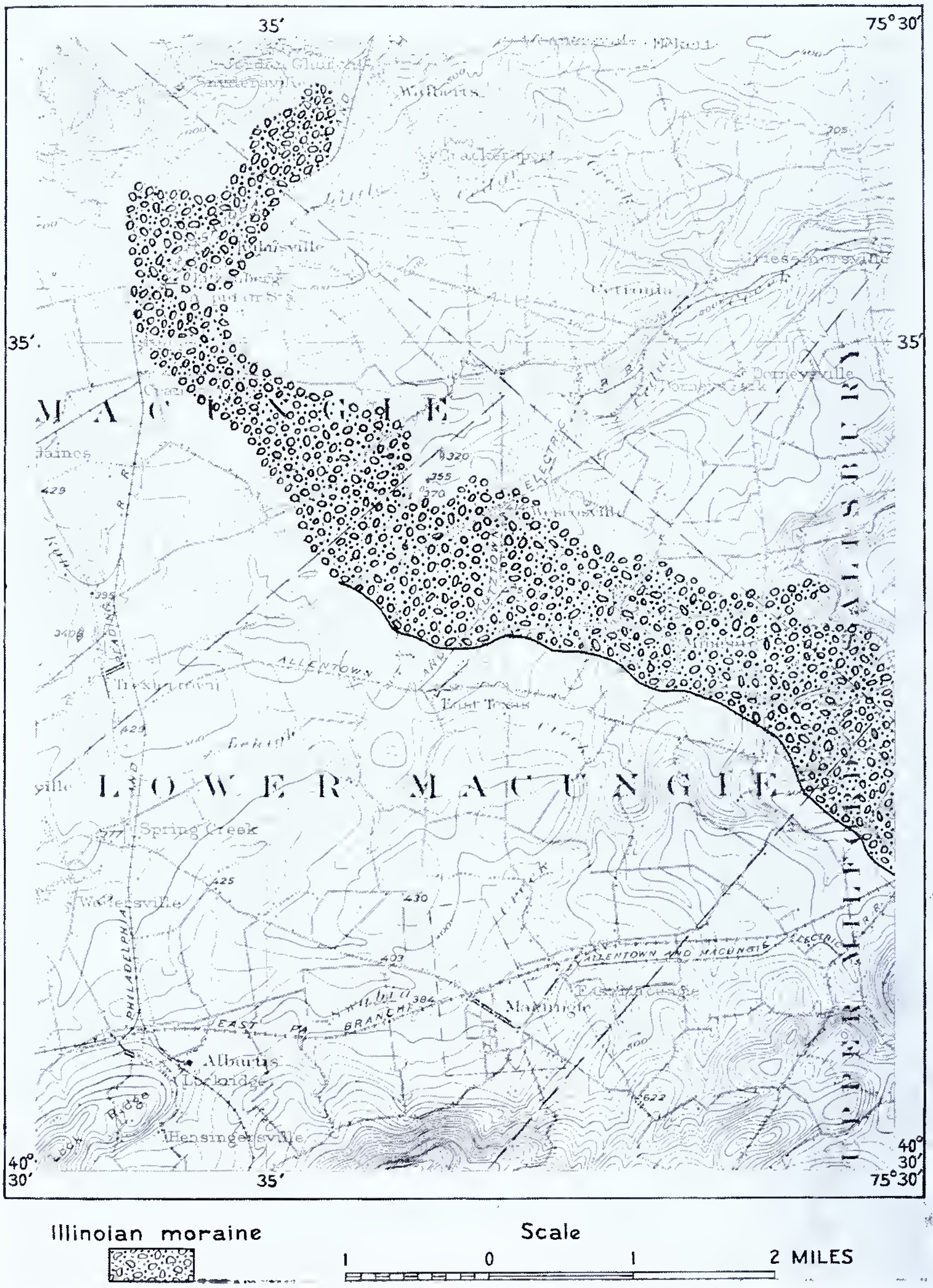

Figure 31. Topographic map of part of Slatington quadrangle showing Illinoian moraines northwest of Emaus.

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[1] Geol. Soc. America Bull., vol. 5, p. 292, 1894.

tain, running westward from Slatington, that carries deposits of till which have the general aspect of the Illinoian till. The westernmost of these deposits noted by the present writer are exposed in railroad cuts between Germansville and New Tripoli, on or near the divide between Jordan Creek and Maiden Creek, which is the divide between the Lehigh and Schuylkill drainage basins. Till deposits are conspicuous from the headwaters of Jordan Creek eastward past Slatedale and in slate pits around Slatington. They lie mainly between the Reading Railroad and Blue Mountain, being scanty south of the railroad, and are restricted to a level but little more than 700 feet above sea level. The altitude is about 700 feet in the railroad exposures near the Lehigh-Schuylkill divide. If the ice covered ground at 700 feet that far west it may have covered the hills south of Slatington that reach 900 feet. It seems probable that the district east of Lehigh River was entirely covered up to the base of Blue Mountain. The height to which the ice rose on the slope of this mountain has not been determined. It seems to have reached a markedly higher altitude on the north border of the lobe, next to Blue Mountain, than on the south border, next to South Mountain.

TOPOGRAPHY OF THE DRIFT

A distinct moraine is found along the border of the Illinoian drift where it terminates on the limestone lowland west of Allentown (Fig. 31). Morainic features are displayed in the Saucon Valley (Fig. 30), from "Iron Hill" in Bethlehem south and west past Hellertown to Friedensville. In its passage across the limestone lowland from Emaus to Chapman the moraine has a width of half a mile to a mile and a relief of 20 to 40 feet above the district outside, which probably represents about the thickness of drift along the moraine. The topography is of a subdued swell and sag type, as if the swells had suffered considerable toning down as a result of relatively long exposure to surface wash. The sags and basins also are not so sharply outlined as in the moraines of Wisconsin drift.

THICKNESS OF THE DRIFT

Except in the morainic part near the outer border, and where it fills valleys, the drift is generally a very thin sheet, scarcely forming a complete cover over the rock formations. It is generally too thin to conceal the basins that had been developed by underground drainage in the limestone prior to this glaciation, and they remain as saucer-like depressions from 3 to 10 feet in depth. In the slate areas depressions have been filled with till to a depth of 30 feet or more, as revealed in the quarrying of the slate. These depressions occupy only a small percentage of the slate area, scarcely as much as that occupied by the basins in the limestone. On the higher parts of the slate area the drift is very thin and patchy.

The greatest thickness of drift of which a record has been obtained was found in a well put down in the west part of Bethlehem by E. H. Williams, Jr. This well penetrated 137 feet of drift, and reached rock at a level 40 feet below the adjacent part of Lehigh River. This record is of interest in showing that the valley erosion had reached its lowest level there before the Illinoian stage of glaciation.

CHARACTER OF THE DRIFT

The Illinoian drift of this district consists mainly of a reddish clayey till. In places it carries sufficient gravel to warrant opening pits in it for commercial use. The clayey part of the till may have been derived largely from the residuary clay left from the solution of the limestone, but most of the stones in the till have come from other formations over which the ice sheet had passed before it invaded the limestone area. On the southern border of the limestone area the drift carries gneiss and other rocks derived from South Mountain.

Williams has given the following description of the till, and interpretation of its derivation.[1] The description appears to apply to a section near Bethlehem.

> It shows a surface clay, unstratified, and carrying rolled stones from the Blue Ridge (Blue Mountain), and beyond (Oneida, Medina, Oriskany, Helderberg, Marcellus, Hamilton, etc.) and covering a till that varies widely in its nature, but is mainly of local stuff, of angular shape, mixed with a greater or less proportion of rolled material similar to that in the clay, and locally with angular masses of the same. This latter rests uniformly on glaciated rock in place. This section may vary by the omission of the till, or by the introduction of local stratified deposits of sand and clay.

Williams appears to have held the view that the residuary clay of the limestone was almost completely gathered up and reworked to form the till, for he found outcrops of the limestone within the glaciated district to be generally fresh rock. He also noted a general similarity of material from top to bottom, described as follows:[2]

> First, the admixture of fresh and oxidized materials at all levels, and the uniformity of oxidation at any point along a vertical section * * *. This curious and persistent admixture proves that oxidation preceded glaciation. In the slate belt the proportion of decomposed slates increases from north to south, and the same is true of limestone in the limestone belt, only chert being found at the south.

In another paper[3] Williams interpreted the surface clay to be a deposit in ponded water, held in front of the receding ice border, to a level corresponding to the lowest pass on the Lehigh-Schuylkill divide, about 500 feet above sea level. He named the hypothetical body of water "Lake Packer" and called the surface clay "Packer clay." The question of the occurrence of such ponding is taken up on a later page.

Williams made the suggestion[4] that drumlins may be present near Bingen, Siegfried, and Northampton, his statement being as follows:

> It has not been fully determined whether the ridges of unstratified gravel at Bingen, Siegfried, Northampton, etc. are drumlins or portions of lateral or terminal moraines. The two latter deposits are on the north bank of the Lehigh, and are 10 to 20 feet thick, from half a mile long, and from a few hundred feet to a half mile wide. The chances are in favor of their being drumlins, and connected with the subglacial drainage of the region.

The present writer could find no drift hills in the vicinity of these places that have the form of drumlins. Furthermore, drumlins are not a product of subglacial drainage.

Several of the deepest exposures of drift in the Illinoian area south of Blue Mountain were examined by the writer and found to exhibit a wide difference in the character of material, as may be seen by the following notes.

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[1] Williams, E. H., Jr., Am. Jour. Sci., 3d ser., vol. 47, p. 34, 1894.

[2] Idem. p. 35.

[3] Williams, E. H., Jr., Geol. Soc. America Bull., vol. 5, pp. 286-289, 1894.

[4] Idem. p. 289.

A large clay pit at a brick plant 1½ miles west of Nazareth, about 25 feet in depth, exposes a brown till carrying only a small number of pebbles, a feature giving it superiority over more stony till for brick manufacture. The limestone pebbles have been leached from the till to a depth of 15 feet, below which they are still present, and the matrix in this lower part is also unleached. This was the only pit examined west of the Delaware in which the depth of leaching is clearly shown. In most exposures the matrix is not sufficiently calcareous to give ready response to tests with acid. Limestone pebbles also are very scarce in some of the exposures so that thorough search is necessary to find one.

In a slate pit in the west part of Slatington there is an exceptional exhibit of drift. The lower 10 to 12 feet is a stony, partially assorted material, probably water-bedded. Above this is about 40 feet of clayey till. This is gray in part of the north wall of the pit to a level within 10 feet of the top, above which it is reddish, but changing to brown near the surface. On the south side of the pit there is 15 to 20 feet of reddish till directly above the assorted material. The color changes upward to brown at about 6 feet from the top. This is the only pit in the Illinoian drift in this region in which gray till has been noted, and the cause of the color has not been determined. It may be due to the incorporation of residuary clay from gray slate. The till of this region is usually brown or reddish from top to bottom even where it is 30 to 40 feet thick. As suggested by Williams, it appears to have been oxidized before it was gathered up and redeposited by the Illinoian ice sheet.

There is an extensive exposure of reddish-brown till along the railroad tracks at "Iron Hill," in the east part of Bethlehem, with a depth of 30 to 40 feet. It is mainly a rather stony till, and includes rocks of various kinds, brought in from distant points to the northeast.

Rauch's pit in Bethlehem, described repeatedly by Williams in his early papers, includes gravel and sand deposits underlying a surface clay, and overlying a sheet of till. The gravel and sand deposits show a cross-bedding with dip to the south, in the direction of drainage from the ice border. This gravel was not well exposed in 1927, at the time of the present writer's visit. It outcrops in the west bluff of Monocacy Creek, a northern tributary of Lehigh River, and at a level about midway of the slope. It is thought by Williams to be restricted to the west side of the valley. The clay cover becomes thicker in passing west from the border of the valley, as shown by the depth penetrated in cesspools to reach the gravel.

A large gravel pit north of the Bethlehem-Allentown electric car line in the east part of Allentown is excavated to a depth of 25 feet. Over the gravel is a thin cover of bouldery clay 2 to 5 feet thick, with stones as much as 3 feet in diameter. In the east part of the pit a thin sand bed underlies the bouldery clay. Between the beds of gravel there are also sandy beds several inches thick at various levels in the walls of the pit. The bedding is horizontal and shows no evidence of disturbance by an overriding ice sheet, a feature taken by Williams to indicate that the bouldery clay was laid down in ponded water outside the ice border, and not directly by the ice sheet. The gravel has a gray aspect, but this seems to be due to the large proportion of light colored rocks in it, rather than to lack of oxidation.

There are extensive clay pits at brick yards in the south part of Allentown. Boulders are conspicuous in the upper 6 feet of the deposit. The state of oxidation is more pronounced in this part than in the less stony underlying till that is drawn upon for brick material. The till is brown as far down as the excavations extend, about 20 feet.

Extensive clay pits have been dug for brick manufacture in the north part of Emaus, on the crest of the moraine that forms the border of the Illinoian drift, but they had been abandoned in 1927, and exposures were not good. The clay seems to carry a large number of boulders, and the surface is undulating with characteristic morainic topography.

There are cuts 6 to 8 feet deep in the till on the highway west of Wescosville on the slope of the moraine which show the knolls there to be composed of bouldery clayey till. Similar material occurs in knolls cut through by the railroad at Chapman.

In a pit at the east edge of Siegersville the drift ranges from 5 feet to 25 feet in depth within the space of a few rods, owing to the unevenness of the underlying rock. It is a rather stony till with many waterworn cobblestones imbedded in a matrix of sandy clay.

An old drift west of Riegelsville in the lower end of Durham Valley probably is of Illinoian age. It is of gravelly character, and exposures show it to be at least 20 feet deep. Its lower limit is about 200 feet above sea level, which is slightly higher than the surface of the later (Wisconsin) gravel terrace on the Delaware at Riegelsville (Fig. 32). It shows markedly deeper weathering than the gravel of Wisconsin age and contains very little limestone compared with the number of limestone pebbles in the Wisconsin gravel. These deposits seem to lie at the southern limit of glaciation in the vicinity of the Delaware Valley.

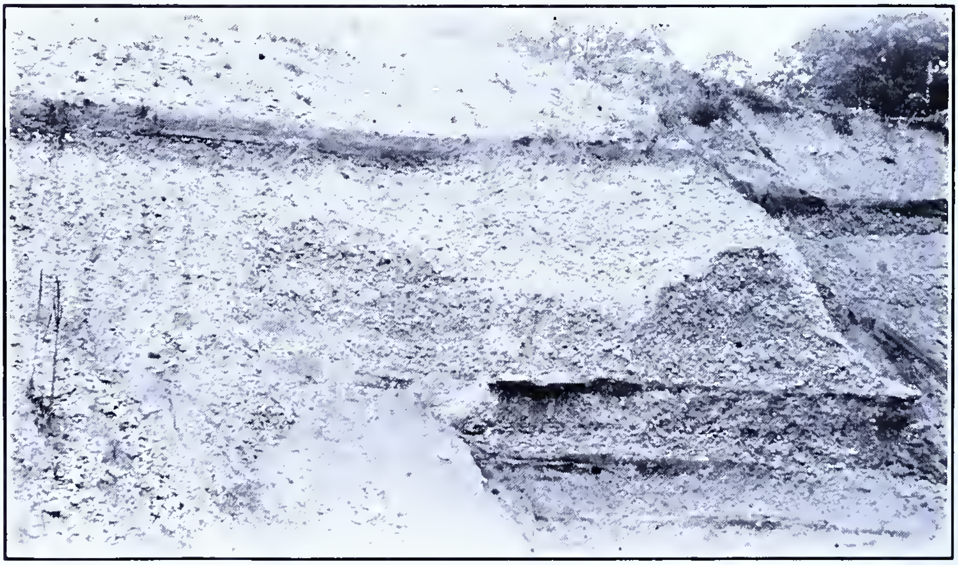

Figure 32. Gravel in pit at Riegelsville on Delaware River. Probably Illinoian below and Wisconsin above the dark band.

WAS THERE A LAKE PACKER?

Williams has interpreted the upper or surface part of the Illinoian drift in the limestone lowland, and within the Lehigh drainage basin, to be a lake deposit, and he has given the name "Lake Packer" to the body of water which he thought occupied the lowland. He inferred that ponding occurred before the ice sheet had reached its culmination, and that it recurred as the ice border melted back across the lowland.[1] He based the presence of such a body of water in some degree on hypothetical grounds, and gave it the altitude of the lowest part of the divide between the Lehigh and Schuylkill drainage basins in the limestone lowland, about 500 feet above sea level. But he also cited places where clay deposits rest on undisturbed gravel, and drew the inference that the clay was not deposited by the ice sheet for if it had been the gravel beds under it would show disturbance. Any lake deposits made during the advance of the ice were covered by glacial material to the extent that the ponded area was invaded and occupied by the ice sheet. The deposits as now exposed are thus restricted by him mainly to material laid down during the retreat of the ice border. This material termed "Packer clay" is described as follows in the paper above cited. From this description it will be seen that the "Packer clay" is of complex and varied character, much like till, and with little resemblance to the ordinary lake deposit.

> The clay is generally a reddish-brown, unstratified, sandy deposit, with a burden of glaciated, angular, and river-rolled material scattered irregularly through it. Very few striated stones have been found in the sections studied, and the bulk of the burden consists of river cobbles and pebbles, with a considerable proportion of perfectly angular fragments, derived from the rocks to the north of the locality where they occur in the clay. In the case of syenitic fragments, they occur near the South Mountain, where they could have been picked up by shore ice and carried a short distance. The greater proportion of the burden, however, are sandstones and chert, with a small amount of limestone and slate. The specimen of striated rock exhibited is from the clay, and shows the general freshness of the burden. The slates are generally fresh within, if oxidized externally, and workable slate can be found 10 feet from the surface, whereas the average depth of decomposed soil over an unglaciated area, or one exposed to long atmospheric action, is from 60 to 75 feet.
>
> The clay deposit varies from a perfectly clean clay to clayey sand as we go from the deep water of the south to the northern shallows It is generally unstratified, but shows local areas of stratification. Its thickness varies from a few inches to twelve feet at West Bethlehem, but the general average is three feet.

The "Packer clay" was thought by Williams to be absent from the part of Saucon Valley west and south of Hellertown. He interpreted this absence to denote that there was no outflow from the Saucon Valley past Leithsville to Durham Valley, and thence to Delaware River. He said that a flow over that divide would have distributed the clays over the Saucon Valley in great bulk. Concerning the state of oxidation of the clay (and this seems to include the till) Williams remarked:

> The high state of oxidation of the clay has been adduced as evidence of its great age, but the argument is worthless in view of the manner in which it was accumulated and the condition of the burden it carries. These glaciated, rolled and angular stones are generally fresh and unoxidized, as just described. We have, therefore, a highly oxidized clay throughout, bearing at all levels fresh material. The mixture is no older than the fresh part, and the oxidation of the clay is either preglacial, from its having been part of the soil of the region (as

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[1] Williams, E. H., Jr., Geol. Soc. America Bull., vol. 5, pp. 286-289, 1894.

gneiss, limestone, and slate all rot to such a clay), or due to oxidation while it was being deposited. Judging from the state of certain portions of the till, the chances are in favor of the former supposition. These fresh fragments antedate the great moraine and show that it also is of recent date. It may be argued that the clay (Packer) is the ordinary boulder clay of subglacial origin. If it were its deposition would have disturbed the stratification of the underlying gravels and sands, and there would not be the great proportion of angular fragments in the burden, nor, further, would we in hundreds of cases find the till shading gradually and conformably into the overlying clay.

Inasmuch as the presence and level of "Lake Packer" was made dependent on drainage over a pass in the limestone lowland outside the Illinoian ice border on the divide between the Lehigh and Schuylkill rivers, and not on a slightly lower pass at Leithsville, between the Lehigh and the Delaware, the present writer gave considerable attention to the features at each pass. The lowest place on the Lehigh-Schuylkill divide is north of Topton at an altitude between 480 and 500 feet (Fig. 33). The pass at Leithsville, between Saucon Valley and Durham Valley, is at 445 to 450 feet (Fig. 30), or fully 30 feet lower than that near Topton. Williams suggested that the Leithsville pass had a higher altitude than that near Topton at the time the ice sheet was present and had later been cut down to its present level. He attributed the lowering to a concentration of drainage from bordering uplands, causing rapid cutting, whereas there was no such concentration of drainage from bordering uplands on the Lehigh-Schuylkill divide. The writer was unable to find evidence of a post-Illinoian lowering of the pass at Leithsville. At this pass the limestone floor has a thin deposit of cobbly clayey material indicating drainage across it of rather weak character. The pass is close to the Illinoian border and the deposit is probably an outwash from the ice sheet that occupied the Saucon Valley. The sluggish drainage is perhaps due to the partial blocking of the lower end of Durham Valley by the ice sheet in the Delaware Valley. It is probable also that the water discharging across this pass was merely that coming from the small ice lobe that occupied the north end of the Saucon Valley. Its level may thus have had no relation to that of the drainage across the Lehigh-Schuylkill divide.

An examination of the Lehigh-Schuylkill divide failed to bring to light evidence of a discharge of water across it. The Reading Railroad cut on the divide at Topton shows a few waterworn cobblestones in a clay deposit, exposed to a depth of 6 to 8 feet. The divide here is below the 500-foot contour and probably about as low as any other place on it in the limestone lowland. The stones are irregularly distributed, and the deposit seems to be such as might result from slope wash from the higher land to the south. In a clay pit in the north part of Topton no pebbles were found. The divide was carefully examined from Topton northward past Five Points, but no deposits indicative of the flow of a vigorous stream across it were found. The present writer is accordingly very doubtful if ponding such as Williams postulated really took place. An examination of the district between the Lehigh-Schuylkill divide and the terminal moraine of the Illinoian drift did not bring to light any deposit that seems attributable to ponding. Furthermore the bouldery clay on the surface of the Illinoian drift appears to be better interpreted as a direct deposit from the ice sheet than as a deposit in ponded water outside the ice border.

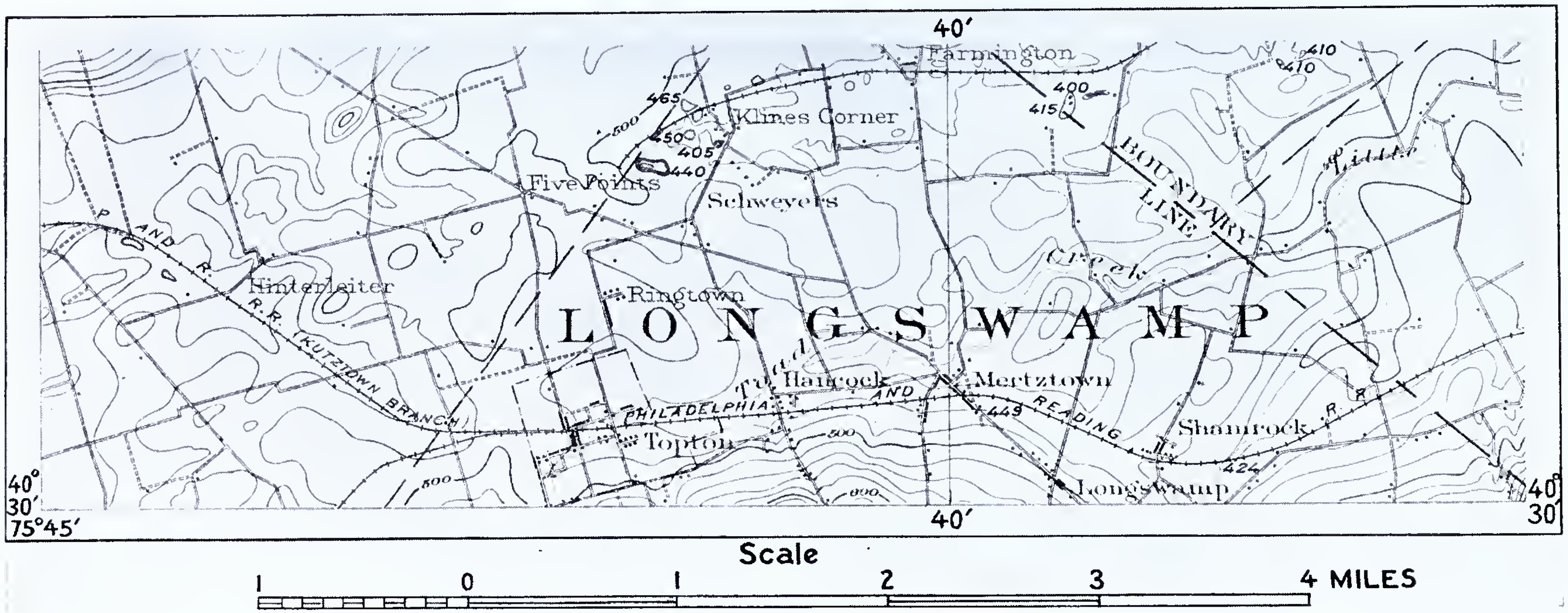

Figure 33. Topographic map of lowest place in Lehigh-Schuylkill divide, near Topton.

As to the disposal of water from the melting of the Illinoian ice lobe, two dissimilar modes of discharge have been considered. One is the escape of the water along the south edge of the ice sheet at the base of South Mountain between Bethlehem and the Delaware Valley. This may have been to a considerable degree submarginal rather than outside the ice edge, and similar escape may have been found along the Delaware from Easton to Riegelsville. The other mode of escape is by underground drainage through the limestone of the outlying district west of the moraine. Much of the present drainage goes through underground channels. Water from a moderate rate of melting of the ice may have been thus disposed of without causing ponding outside the ice border.

ILLINOIAN DRIFT NORTH OF BLUE (KITTATINNY) MOUNTAIN

DISTRIBUTION

The limits of Illinoian drift in the district farther north are less clearly defined than in that south of Blue (Kittatinny) Mountain. No such definite moraine is at the border as that which crosses the limestone lowland. The ice seems to have projected several narrow tongues into the valleys of western tributaries of Lehigh River and caused a ponding in them to sufficient height to discharge across low cols into the Little Schuylkill River. Along these lines of discharge there is more or less cobbly material, so it is difficult to draw the line between deposits laid down directly by the ice and those rafted beyond the ice border on blocks of ice floating in the ponded waters. Where there is a till deposit the presence of the ice sheet may be inferred, but where only cobbly material is found the mode of deposition and relation to the ice border are somewhat uncertain.

The ice sheet seems to have covered Pocono Mountain and its continuation, Pohopoco Mountain, as far west as the vicinity of the Lehigh Valley. It also extended south of the mountain about to the valley of Pohopoco Creek. Glacial deposits are conspicuous on the rather steep south slope of the mountain, and at various levels on the lower country to the south as far as the creek valley. This district is strikingly in contrast to that south of the creek where no till deposits were noted in several traverses across it to the base of Blue Mountain. This distribution of the drift seems to indicate that the ice sheet came from the north into the district south of Pocono Mountain and not from the east.

In the Lehigh Valley the ice seems to have extended to Palmerton, near the water gap in Blue Mountain. As already indicated, there appear also to have been ice tongues extending into the lower ends of western tributaries of Lehigh River above the Lehigh water gap.

There is some uncertainty as to the extent of the Illinoian ice sheet over the northern part of the Hazleton quadrangle and southern part of the Wilkes-Barre quadrangle, for pre-Illinoian as well as Illinoian till seems to be present there. Thus deposits of clayey till in the valley of Black Creek, in the northwest part of the Hazleton quadrangle and northeast part of the Mahanoy quadrangle seem likely to be of probably pre-Illinoian age, and to lie outside the limits of the Illinoian glaciation. The same is true of deposits in the headwaters of Hazle, Beaver, and Quakakee creeks in the Hazleton quadrangle. Till deposits in the south part of the Wilkes-Barre quadrangle as far west as the vicinity of Zehner are referred with some confidence to the Illinoian glaciation. They are so thick that H. C. Lewis included them in the terminal moraine of the later (Wisconsin) glaciation. The deposits, however, are more deeply weathered than those in the Wisconsin moraine, and do not have the sharp knolls characteristic of that moraine. This till is a well defined deposit up to an altitude of fully 1,750 feet in the vicinity of Zehner.

THICKNESS OF THE DRIFT

The Illinoian drift of the district north of Blue Mountain is far from being a continuous sheet, yet it is much less patchy than the pre-Illinoian drift. On uplands the thickness is usually less than 10 feet and in few places reaches 30 feet. But in the valleys the thickness locally exceeds 150 feet. The deepest drift record obtained is that of a well at Lehighton in Lehigh Valley. It penetrated 178 feet of drift and there is some uncertainty as to rock being reached at this depth. The well mouth is about 620 feet above sea level, so it went down to about the same altitude as Lehigh River, which is 440 feet at Lehighton.

CHARACTER OF THE DRIFT

The upland drift is generally a reddish clayey till in which local rocks embedded in the deposit greatly outnumber rocks of distant derivation. In the valleys the till is usually less clayey, or contains more cobblestones. There are few places in which the drift shows clearly a sorted condition. Its appearance is such as to indicate lack of free escape of water from the border of the ice. This is a natural condition, because the Lehigh Valley south of Blue Mountain was covered by the Illinoian ice sheet at the culmination of the Illinoian glaciation, which was probably reached at about the same time on the north and south sides of the mountain. On Pocono Mountain, east from the Lehigh Valley, the till is rather thickly set with local rocks of various sizes, and but slightly rounded.

Very few excavations have been made in the Illinoian drift in this region, for the deposits seem to be of little commercial value. There are scattered exposures along streams, and cuts of slight depth along railways and highways.

A railway cut in Palmerton exposes about 20 feet of reddish-brown clayey till over a red shale. This deposit lies in what appears to have been an old channel of Aquashicola Creek, north of the present channel. Its rock bed is about 40 feet above that of the present channel, or 420 feet above sea level. A more cobbly drift is present on the slope north of this railway cut, up to an altitude of about 500 feet, and this seems to be the upper limit of Illinoian drift here. It is about 200 feet lower than that on the south side of Blue Mountain near the Lehigh water gap. It is also lower than at points up the Lehigh Valley in the direction from which the ice came.

Red clayey till is exposed at intervals along the east side of Lehigh Valley from Palmerton up to Weissport, but on the west side there are precipitous rock bluffs nearly all the way to Lehighton. On a ridge south of Weissport, between Pohopoco Creek and Lehigh River, a clayey drift with numerous cobblestones embedded in it is present up to fully 560 feet above sea level.

In Lehighton, drift carrying many well rounded stones is present up to about 300 feet above Lehigh River, or about 740 feet above sea level. The well referred to above, which penetrated 178 feet of drift, is on the property of Mrs. Gledhill, on ground about 620 feet above sea level. A mile above Lehighton, on the slopes of Beaverdam Run, cuts on the abandoned electric railway line from Lehighton to Mauch Chunk expose deposits of cobbly drift 15 to 20 feet thick. Those on the north side extend up to an altitude of 880 feet. At lower levels near Beaverdam Run the drift is more clayey.

The highway leading east from Weissport past Kresgeville runs near the southern limit of the Illinoian drift, and makes cuts in it a few feet deep between Beltzville and Kresgeville. The till is in few places more than 10 feet thick. The best exposures are on the tops of projecting points on the south side of Pohopoco Valley. They show cobble and boulders in a clayey matrix. East of Kresgeville highway cuts in shale show great disturbance, presumably as a result of the ice invasion. In some cuts 20 feet deep there is scarcely a trace of the original bedding, the beds being jumbled and broken to bits, yet little if any foreign rock material is present.

Along the highway leading from Effort up Pohopoco Creek to Pocono Mountain a reddish clayey till thickly set with boulders and cobblestones is conspicuous on the mountain slope as well as in the valley. The deposits are conspicuous in a recess between Pohopoco Mountain and Pocono Mountain up to an altitude of 1,850 feet, where the highway passes into Tunkhannock Township. On the tableland in this township the road cuts are scarcely 5 feet deep, and the material exposed is largely angular and seems to represent local rock formations, but the tableland was probably overridden by the Illinoian ice sheet.

On the north side of Mud Run, in the south part of the Stoddartsville quadrangle, from Swamp Run westward past Albrightsville there are deposits of reddish clayey till containing many cobblestones and small boulders. These deposits are mainly below an altitude of 1,700 feet, but patches of till were noted near the Stony Point fire tower, west of Albrightsville, at 1,760 feet. In places the till seems to have a thickness of 15 to 20 feet.

A sheet of till covers the tableland southward from Albrightsville clear to Mauch Chunk. At Christmans a boulder of red sandstone 8 by 8 by 4 feet in diameter was noted near the sawmill. Most of the rock material of the till is somewhat angular and came from the local indurated sandstone. The bedrock carries a mantle of clay several feet thick in which the indurated sandstones are embedded. At the Behrens farm, 4 miles northeast of Mauch Chunk, wells go down about 20 feet to solid rock on ground about 1,600 feet above sea level. A road leading southward from the Behrens farm down the slope to the head of Long Run is on a deposit of clayey drift all the way, and descends from 1,600 to 870 feet. There are scarcely any outcropping ledges on the rather steep slope. A strip of rather thick drift that extends along the base of the mountain from the head of Long Run eastward past Walcksville was examined as far as Pine Run near the upper Lehighton reservoir. South of the reservoir, in the northeastern angle of Franklin Township, the drift has a subdued swell and sag morainic topography in a pass between Sawmill Run and Pine Run, at an altitude between 800 and 900 feet. It is of clayey character and carries many small rounded stones.

Illinoian drift appears to be present in Bloomingdale valley west from Mauch Chunk, but the western part of the valley is probably outside the limits of the Illinoian invasion. The valley has a coating of till westward beyond the divide between the Lehigh and Little Schuylkill drainage basins. The exposures are scarcely deep enough to throw light on the extent of the Illinoian invasion. The best exposures are 2 to 3 miles west of Mauch Chunk and show a red clayey till 15 to 20 feet or more in depth. These exposures are between 800 and 900 feet above sea level and about 300 feet below the water parting in the valley, which is 1,150 feet above sea level. Mauch Chunk Creek descends 300 feet in its lower 2 miles in passing down from Bloomingdale Valley to the Lehigh River, and there is very little drift along this part of its course.

The valley of Nesquehoning Creek, which joins the Lehigh Valley just above Mauch Chunk, differs from that of Mauch Chunk Creek in being graded down to the same level as Lehigh Valley with no rock gorge at its lower end. It carries deposits of red clayey till of probable Illinoian age as low down as 700 feet, where the Mauch Chunk and Hazleton highway crosses, 1½ miles above the mouth. At this place the road cuts expose about 20 feet of till. Near the mouth of the creek boulders and cobbles are exposed up to a level 50 to 75 feet above the Lehigh River bottom. Till is present on the headwaters of Nesquehoning Creek, but it probably is pre-Illinoian. It covers land that is 1,100 to 1,200 feet above sea level, 500 to 600 feet higher than Lehigh River, and 10 to 12 miles from the river. Because of the presence of pre-Illinoian till it may be a difficult matter to determine the limits of the Illinoian drift here as well as in other western tributaries of the Lehigh.

A thin sheet of drift east of Weatherly, on the north side of Black Creek Valley, seems likely to be Illinoian, and Illinoian drift may be present in a lowland between Weatherly and Hudsondale, where there is a nearly continuous but thin deposit of red till. West from Hudsondale there are a few patches of till in the lowland north of Quakakee Creek, but they may prove to be pre-Illinoian. The altitude is between 1,200 and 1,300 feet, or 500 to 600 feet lower than bordering parts of the Broad Mountains on the south and Spring Mountain on the north.

The Illinoian drift appears to cover a lowland north of Spring Mountain a little farther west than the junction of the Hazleton and Beaver Meadow branches of the Lehigh Valley Railroad. It is a red clayey till and is exposed in cuts 6 to 8 feet deep along the Hazleton branch. It carries numerous striated stones and also waterworn cobbles and boulders. The altitude is above 1,300 feet, and parts of the lowland are above 1,400 feet. An open passage over a mile wide extends back to this locality from Lehigh River through Lehigh and Lausanne townships into the eastern end of Banks Township. Farther west there are only narrow passages between prominent ridges, and it is doubtful if the Illinoian ice extended far into them. There is some till farther west on a tableland south of Hazleton around Audenreid, but this is probably pre-Illinoian. The tableland stands 1,700 to 1,800 feet above sea level.

The drift deposits around Zehner form a nearly continuous sheet, and are well displayed up to an altitude of 1,750 feet. A little sand and gravel are interbedded with the red till. A pit a quarter of a mile north of Zehner gets sand under 5 or 6 feet of red till. In exposures along a road leading west from White Haven on the north side of Green Mountain, striated boulders and cobblestones are conspicuous. The till, however, is a thin deposit, in places only 6 to 8 feet thick. It becomes thicker toward the head of Linesville Creek, and is thick from Zehner north to the base of Yeager Mountain. The red color of the drift is due in part to the presence of red rock material, but the drift is more deeply weathered than in adjacent deposits of Wisconsin drift, in which red rock material is present in notable amount.

ILLINOIAN GLACIAL DRAINAGE

As the lower end of the Lehigh Valley, south of Kittatinny Mountain, was covered by ice at the culmination of the Illinoian glacial stage, it would not be open to discharge of water from the part of the ice sheet north of the mountain until considerable shrinkage had taken place in the southern lobe. But the valley of Little Schuylkill River lay outside the limit of Illinoian glaciation, in a position favorable for receiving the discharge from ponded waters in western tributaries of Lehigh River north of Kittatinny (Blue) Mountain. There are passes at the heads of these tributaries at relatively low altitudes from which streams lead into Little Schuylkill Valley.

The southernmost pass between the Lehigh and Little Schuylkill valleys is at Kepner on the Lehigh Valley Railroad, at the head of Lizard Creek, at an altitude of only 790 feet. There does not seem to be clear evidence of vigorous drainage over the pass. Slight cuts at the pass expose clay instead of sand or gravel, and no distinct trench has been cut across it. The valley of Lizard Creek carries wash from Blue Mountain, in which stones of all sizes and degrees of rounding are embedded in clayey or loamy material. It is questionable whether there are glacial deposits in the valley. There may also have been but slight ponding here if a neighboring pass at the head of Mahoning Creek had free discharge for waters ponded in its valley.

The pass at the head of Mahoning Creek is slightly higher than that at the head of Lizard Creek, being above the 820-foot contour (Fig. 34). Cobblestones being strewn over its slopes east of the pass, the evidence of ponding is clearer than on Lizard Creek. There is also a rather wide passage from the head of this creek into Little Schuylkill Valley, less than a mile distant and 140 feet lower.

In Bloomingdale Valley the altitude of the pass between Mauch Chunk Creek and Owl Creek is above 1,140 feet (Fig. 34). There is a cobbly and bouldery deposit along Owl Creek west of this pass, well exposed by the excavation at the dam for the Tamaqua waterworks reservoir, where the deposit is 5 to 15 feet thick. It is possible, however, that this deposit is connected with pre-Illinoian glacial drainage, though it may be found that ponding with discharge down Owl Creek occurred in both the Illinoian and the pre-Illinoian stages of glaciation.

The pass at the head of Nesquehoning Creek is between 1,080 and 1,100 feet above sea level and is at the brow of the bluff of Little Schuylkill River, about 300 feet above the stream. (Fig. 34). This

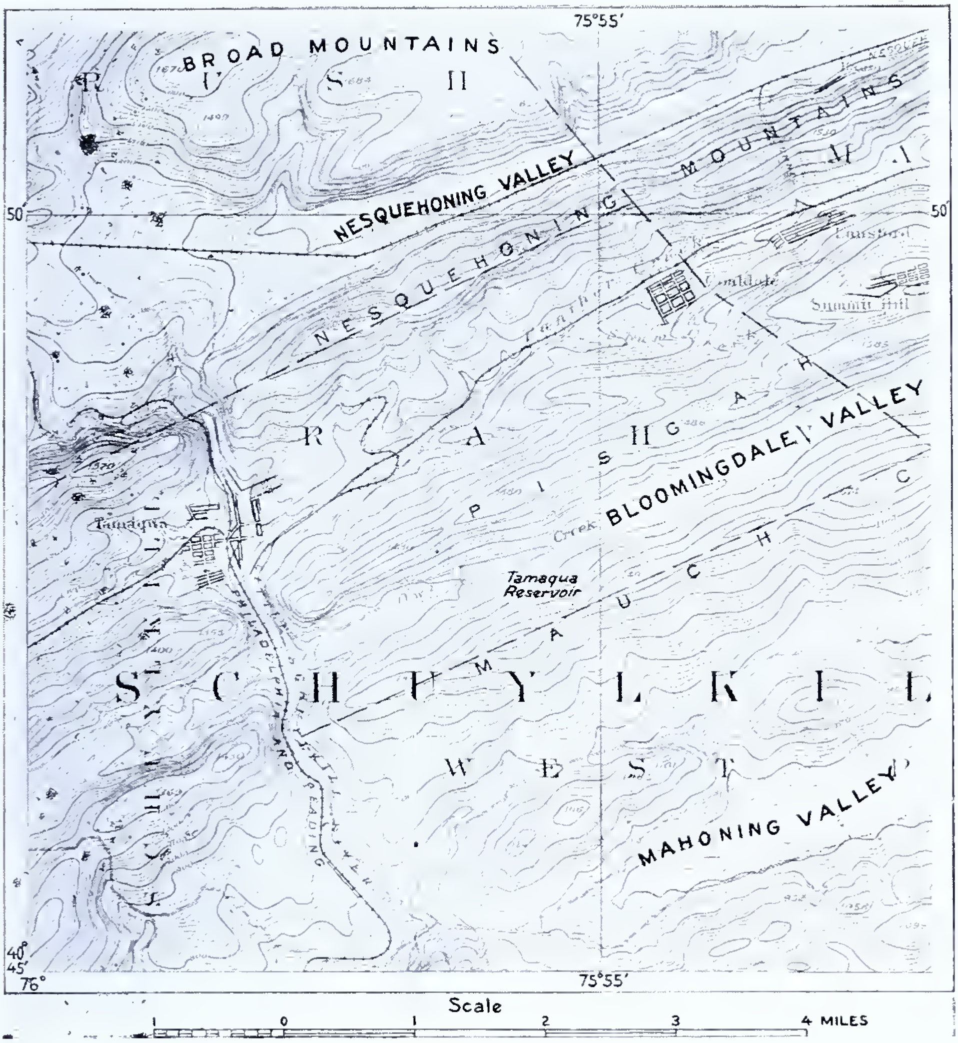

Figure 34. Topographic map of part of Hazleton quadrangle showing passes between Lehigh and Little Schuylkill drainage basins.

pass was not examined in the field but the contours of the Hazleton topographic map give the appearance of a line of discharge there. This pass is within the limits of pre-Illinoian glaciation, as shown by till deposits in a mile-wide lowland west and north of it, shown on the Hazleton map. But it may also have served as a line of discharge for Illinoian drainage from Nesquehoning Creek into the Little Schuylkill valley.

The pass at the head of Little Schuylkill River is above the 1,220-foot contour, but only a little above that level for a width of nearly a mile. Whether or not the Illinoian ice reached to this pass has not been determined, but it seems highly probable that water discharged from it down Little Schuylkill valley. In the pre-Illinoian glaciation the headwater part of Little Schuylkill valley was covered by the ice sheet, as indicated below.

To the north of the head of Little Schuylkill River there are passes at rather high altitudes between tributaries of the Lehigh River and of the North Branch of Susquehanna River. One at Hazleton is above

1,620 feet, and one at Eckley is just under 1,600 feet. The Illinoian ponding may, perhaps, have been high enough to give discharge across one or both of these passes. A deposit of sandy, loamy material in the pass at Hazleton may prove to be connected with such a discharge. The pass at Eckley has a rock floor and is in the form of a swale which may have been swept clean by the flow of a stream across it but it does not carry definite deposits of sand and gravel. Westward from this pass along Black Creek valley there are deposits of red till that are thought to be pre-Illinoian. The passes in the southern part of the Wilkes-Barre quadrangle between the Lehigh and Susquehanna drainage basins are still higher than those near Hazleton and Eckley, and it is doubtful whether there was Illinoian drainage through them, at least until the ice border had retreated past Zehner. A pass between Green Mountain and Yeager Mountain half a mile north of Zehner stands only 1,420 feet above sea level but it exhibits unmodified glacial topography, and does not seem to have been utilized as a line of discharge for glacial drainage.

THE ILLINOIAN DRIFT IN NEW JERSEY

DISTRIBUTION

The drift in New Jersey that seems referable to the Illinoian stage is exposed in a narrow strip outside the Wisconsin drift border in the elevated district between Hackettstown and Dover and in lowlands either side of this district. In the lowlands it extends farther than on the upland.[1] In the Delaware Valley and on its immediate borders the drift appears to extend about to the limits of glaciation, near Riegelsville. On the Raritan its limits are somewhat uncertain. It may extend to Califon, though this would be a remarkable protrusion in a region of such moderate relief. In the Passaic basin it is present as far west as a group of kames at Bernardsville and Basking Ridge. South of the Passaic basin its limits seem to be inside those of the Wisconsin drift. Within the limits of the Illinoian drift as above outlined there are prominent rock hills on which no definite deposits of Illinoian drift have been noted, and some of the highest ones may not have been completely covered by the Illinoian ice sheet.

A deposit of till has been reported by Freeman Ward to underlie the Wisconsin gravel deposits in the Delaware Valley a few miles below Phillipsburg, and was interpreted by him to be of Wisconsin age.[2] But it lies several miles outside the terminal moraine of Wisconsin drift, and, as expressed in a criticism of the paper,[3] it seems to the present writer to be of Illinoian age. It is within the limits of the Illinoian drift, and there seems to be no reason for referring it to a later glacial stage.

TOPOGRAPHY OF THE DRIFT

In general the Illinoian drift in New Jersey has a plane surface, and its border is not marked by a definite terminal moraine. But between Bernardsville and Basking Ridge there are kames of considerable prominence at the border of the drift, and Salisbury's maps show low kames in the Passaic basin. Those near Bernardsville were noted in the Annual Report of the State Geologist for 1880 (pp. 84-85), and described as follows:

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[1] For maps and description see: Salisbury, Rollin D., The glacial geology of New Jersey: Geol. Survey of New Jersey, vol. v., 800 pp. and maps, 1902.

[2] Ward, Freeman, A Wisconsin ice tongue in the Delaware Valley: Am. Jour. Sci., 5th ser., vol. 18, pp. 446-448, November 1929.

[3] Leverett, Frank, Probable Illinoian till beneath Wisconsin gravel in the Delaware Valley: Am. Jour. Sci., 5th ser., vol. 19, January 1930.

> Between Bernardsville and Basking Ridge there is a singular ridge of drift which runs southeast to the Basking Ridge railroad station. It is three-eighths of a mile long and a quarter of a mile wide, and is 100 feet above the railroad, or 475 feet above mean tide level. Its outlines are uniform and its surface smooth, consisting of a reddish sandy loam mixed with gravel, cobblestones and scattering boulders. These latter are mainly of crystalline rocks of the Highlands, but there are also many of Green Pond Mountain conglomerate and of red sandstone. They range from 6 inches to 3 feet in length. No indications of glacial action were observed on any of them. The cut in the southeastern face of another hill east of this ridge and north of the Madisonville road shows the boulder drift at the top, 5 to 8 feet thick, lying upon a yellow sand. Both of these hills look like mounds of glacial drift. But they may have come from the Highlands to the northwest. There is considerable drift on all the lower grounds in the vicinity of Basking Ridge, but none on the higher trap ridges.

These drift hills have now been opened by deep excavations, one 50 feet deep, which expose till as well as sandy and gravelly deposits. These deposits seem to be at the southwest border of an ice lobe that covered the Passaic basin in a district outside the Wisconsin drift. It is evident that they should not be included in that drift. They are about 8 miles from the Wisconsin drift border, and the deposits are decidely more weathered than those of the Wisconsin drift.

THICKNESS OF THE DRIFT

Over much of its exposed area the Illinoian drift has a thickness between 10 and 20 feet. Where it fills old valleys it is in places much thicker. It is also thick in the kames near Bernardsville, there being probably 100 feet beneath their highest points. Where a definite sheet of till is lacking there is usually a coating of bouldery loamy material from 1 to 5 feet in depth over the rock formations. The lack of a till coating does not, in some places at least, seem to be due to subsequent erosion, but rather to an original patchy distribution. The Illinoian till is still present on some steep slopes, in situations favorable for erosion, thus testifying to the moderate amount of erosion since Illinoian time.

The valleys in which Illinoian till is present were cut to nearly their lowest depth in New Jersey before this deposit was laid down (Fig. 32). In this respect the post-Illinoian valley deepening on the Delaware and Raritan drainage systems is in contrast to that on the Susquehanna, though the deepening of the Susquehanna Valley has been moderate, being only about 60 feet in much of the course where Illinoian terraces are present.

CHARACTER OF THE DRIFT

The Illinoian drift in New Jersey, like that in eastern Pennsylvania, is very largely a reddish clayey till, with a moderate inclusion of coarse rock fragments. Gravel in sufficient amount to be of commercial value has been found in it in only a few places. The gravel pits examined are the following:

Two pits in the kames near Basking Ridge and one in the east part of Bernardsville, and a pit at a lower level east of the kames, two pits near Dover, and a pit at Springtown, 5 miles southeast of Phillipsburg. In these pits opportunity is afforded to determine the depth of leaching, and degree of alteration of the rocks, and thus to make a comparison with changes exhibited by the Wisconsin drift. The limestone pebbles have been pretty thoroughly dissolved to a depth of about 12 feet, and alteration is pronounced to a depth of 25 feet or more. In places, especially in the large pit at Springtown, the alteration has been such as to change impure limestone pebbles to ochre pebbles of light weight.

It was noted with some surprise that the rocks in the deeper part of a pit in the kame at Basking Ridge show more marked decay than those within 10 feet of the surface. The cause for this difference is not apparent. There is no reason to think that the basal portion of the kames pertains to an earlier drift than the surface portion. In fact the kames seem to be unquestionably the product of a single glacial stage.

A small pit north of the highway in the eastern part of Bernardsville shows gravel beds that have been shoved into a nearly vertical position, probably through the action of the ice sheet. This is a feature of common occurrence in kames.

The gravel in the pit south of the highway just east of Bernardsville has a fresh aspect at moderate depth. It is below the level of the glacial Lake Passaic, connected with the Wisconsin glaciation, but seems to be an earlier and independent deposit. The lake beach which is exposed at the west end of the pit shows the characteristic wave-built form with sharply dipping beds resting on the coarser horizontally bedded gravel which forms the body of the pit. The lake deposit is only 3 to 5 feet thick, while the underlying gravel has been excavated to a depth of 20 feet without reaching its base.

In a pit on the bluff of Mill Brook, 3 miles south of Dover, the gravel is weathered and stained to a depth of 10 to 12 feet, below which its aspect is about as fresh as that of Wisconsin gravel, and limestone pebbles are still present. The gravel in a pit near the southeast limits of Dover is considerably altered to nearly the full depth of the pit, 30 feet, but the color is grayish brown, indicating relatively light oxidation. In the large pit at Springtown although limestones are altered down to a depth of 25 feet the matrix is of grayish brown color giving the gravel a rather fresh aspect.

ILLINOIAN GLACIAL DRAINAGE IN NEW JERSEY

The valleys in New Jersey that lead away from the Illinoian drift border carry gravel only at low levels, usually less than 50 feet above the stream, but Salisbury interpreted a considerable part of the gravel to be of pre-Wisconsin age. In the Pleistocene maps of the Raritan and Passaic folios he classed it as "older alluvium." There seems to be nothing at higher levels to correlate with the Illinoian glaciation. The gravel of Wisconsin age was chiefly deposited near the moraine, except on the Delaware River where it is present at least as far south as Trenton. The older gravel is more earthy than the gravel heading in the Wisconsin moraine, and was termed "clayey gravel" by Salisbury. The difference may be due to greater weathering in the older deposit.

In places on the Delaware River pebbly material is present at levels considerably higher than the Wisconsin gravel train. But this material is probably pre-Illinoian. The rock shelves on which it is preserved are reduced to narrow remnants of the old valley floor, a reduction that seems to require a time much longer than post-Illinoian time. The Illinoian glacial drainage deposits on the Delaware may not stand above the Wisconsin gravel train. This is 50 feet or more above the present stream as far down as Trenton.

PRE-ILLINOIAN OR JERSEYAN DRIFT

DISTRIBUTION

The pre-Illinoian drift is regarded as the westward extension of an old drift in New Jersey to which Chamberlin and Salisbury applied the name Jerseyan in their Geology, issued in 1906, and which had been previously mapped and described as the "Extra morainic drift," in the New Jersey Geological Survey reports. Its limits in New Jersey were determined with some care by Salisbury and his assistants, and set forth on maps issued by the State Survey. The limits in eastern Pennsylvania are still a matter of some uncertainty.

It was thought by E. H. Williams, Jr. that the limestone lowland and the slate formations south of Blue Mountain were glaciated about as far west as the valley of the Schuylkill River above Reading, but the present writer is doubtful whether the ice extended so far west. At least he could find no clear evidence of glacial action in several traverses across the part of this district west of the Illinoian drift limit. Williams interpreted a deposit of stony and clayey material along the north base of South Mountain, from Emaus to the vicinity of Reading as a "lateral moraine." This deposit, however, seems to be restricted to the immediate base of the mountain, and to be made up largely, if not entirely, of material derivable from the mountain slope. The stones in it are coarse next to the mountain, and become finer and scarcer toward the plain. It thus seems to the writer to be referable to ordinary slope wash from the mountain, and not dependent upon glacial action. No till or erratic material was found on the limestone lowland or the slate hills outside the limits of the Illinoian drift. Owing to the remoteness of the pre-Illinoian glaciation almost complete removal of its deposits would have been possible if they were originally scanty. The present writer is therefore disposed merely to question, but not to deny the westward extent of these deposits to the Schuylkill River, in the district south of Blue Mountain.

On the north side of Blue Mountain the pre-Illinoian drift is present in the headwaters of Little Schuylkill River, above Tamaqua, and on the divide between the Lehigh and Susquehanna drainage basins north of the headwaters of Little Schuylkill and Schuylkill rivers. It is also present in the valleys of western tributaries of the Lehigh from the Broad Mountains southward. To what extent it is present on the Broad Mountains has not been determined. It appears to be present between the Nesquehoning and Pisgah mountains, in the vicinity of Lansford, Coaldale and Tamaqua. (Fig. 34). Farther south, from Mauch Chunk Ridge to Blue Mountain, it has not been noted, but may be found by more detailed search.

The pre-Illinoian glaciation may have reached a little outside the

Illinoian and to a somewhat higher altitude in the part of the Lehigh drainage basin south of Blue Mountain even though it had not the extension into the Schuylkill drainage basin assigned by Williams. This interpretation seems favored by the fact that from the Delaware valley eastward in New Jersey and also north of Blue Mountain the pre-Illinoian glaciation extends beyond the Illinoian. As determined by Salisbury and his assistants, the southern limits of the pre-Illinoian or Jerseyan drift run eastward from Riegelsville, on the Delaware River to a point below Clinton, N. J. on the Raritan River, and along the north side of the Raritan to First Watchung Mountain, near Somerville, but it was not noted east of that mountain.

THICKNESS OF THE DRIFT

The pre-Illinoian drift, as now preserved, is generally a thin and patchy deposit, and in wide areas it appears to be represented only by scattered boulders and smaller erratics. The thickest deposits noted in New Jersey scarcely exceed 30 feet, and the patches of till, as mapped by Salisbury and his assistants, in the New Jersey reports occupy less than 10 per cent of the surface.

In eastern Pennsylvania the thickness is commonly between 5 and 15 feet, where the drift is best preserved, and it is a definite deposit in less than 10 per cent of the area that is thought to fall within its limits. However, a single exposure was noted in which this drift has a thickness of about 80 feet. This is near the head of Silver Brook, a northern tributary of Little Schuylkill River, about half a mile south of Haddock, on the highway leading from McAdoo to Tamaqua. It fills a narrow gap in a rock ridge about 100 yards in width, and extends from a point above the 1,500-foot contour down about to the 1,400-foot contour, filling a channel sloping southward. It is banked against a steep rock bluff where the road enters it at the north, there being 35 to 40 feet of drift on the east side of the road and bare rock on the west side. The rock drops off a few rods farther south, and there fully 80 feet of drift is exposed on the east side of the road, and it extends down below the road to the creek bed on the west side. The deposit is a loose-textured rather stony till, including stones of all sizes from small pebbles up to boulders several feet in diameter. Many of the pebbles and boulders are well rounded. The deposit is to be classed as till rather than assorted material, and thus seems to have been laid down directly by the ice sheet. The presence of a deposit of such thickness naturally raises the question whether there may have been originally a general coating of drift of considerable thickness in that region which has been almost all removed by erosion in the long period since its deposition, but which happened to be preserved in this headwater part of a small drainage basin where erosion has been least effective. On the whole, it seems more probable that there was generally a thin deposit of drift, but that here conditions were favorable for greater accumulation.

From the fact that the Illinoian drift, which has suffered only a moderate amount of erosion, is far from being a continuous sheet, wide areas being represented by scattered boulders with little or no accompanying till, it seems natural to infer that the pre-Illinoian deposits were of similar scantiness in parts of the area which they occupy outside the Illinoian limits. Even the Wisconsin drift is very scanty over a considerable part of its area in New Jersey and eastern Pennsylvania where rock prominences carry only scattered boulders, and there is no indication that they have been denuded by erosion of the drift.

CHARACTER OF THE DRIFT

The drift on the uplands is usually clayey and rather thickly set with small stones. These are mainly of local rock and show very little water wear. It thus becomes difficult in places to decide whether the deposit is glacial or merely a residuary deposit. There are, however, striated stones in some of the exposures which indicate their glacial derivation. The variety of stones in some places is so great as to involve considerable transportation by glacial action, especially on elevated uplands where stream action is ruled out. There are also places, as at Morea, where the residuary material has been rubbed off and fresh rock surface exposed.

A cut on the Reading Railroad at the divide between the Schuylkill and Little Schuylkill rivers southwest of Tamaqua, apparently near the limits of glaciation, is about 12 feet deep in a clayey deposit in which some waterworn cobbles and also striated stones are present. The largest rounded stones are 7 or 8 inches in diameter.

In the northeast part of Tamaqua a rather flat area on a spur 200 feet above the river (Fig. 34) carries a deposit of reddish stony clay, exposed by gullies to a depth of 5 to 10 feet. This probably is of glacial derivation, though no striated stones were found in it. Similar clay was noted on the south side of Panther Creek in Coaldale and Lansford. It is exposed in road cuts, gullies and mine caves. The best exposures are at 1,000 to 1,100 feet above sea level. On the flat area at the head of Nesquehoning Creek 2 to 4 miles northwest of Tamaqua there is a red clayey till at least 10 to 15 feet thick, as exposed in railroad cuts near the Hazleton and Tamaqua highway.

The ice sheet probably covered the lowland bordering Locust Creek in the southeast part of the Mahanoy quadrangle, but drift deposits are very scanty in the lowest part of the drainage basin. At higher levels on the south and west borders of the drainage basin deposits of stony clay, probably of glacial derivation, have a thickness of 10 feet or more. Those on the south border were noted in passes between Locust Creek and Schuylkill River north of Brockton and Tuscarora, at about 1,400 feet above sea level. At the head of a branch of Locust Creek, 2 to 3 miles east of New Boston, on a road leading eastward, cuts were examined which show shale fragments as well as conglomerate pebbles in a clayey matrix. The outcrop of the shale is farther east, and at a lower altitude than these exposures. The shale fragments thus seem to have been carried by glacial action to the higher altitude. The cuts are about 1,600 feet above sea level.

As shown in the numerous exposures around the mines at McAdoo, Audenried, Treschkow, and Jeansville, a stony clay 8 to 15 feet thick forms a nearly continuous sheet on the gently undulating tableland, at an altitude between 1,700 and 1,800 feet. This tableland is drained westward to the Susquehanna and eastward to the Lehigh, and erosion has been relatively light over it. It is thus a favorable area for the retention of residuary clay as well as of glacial deposits. To what extent the deposit has been affected by glaciation is not clear to the writer.

In the headwaters of Schuylkill River, near Brockton, deposits of stony clay were found on a terrace 40 to 60 feet above the stream. The deposits are 8 to 10 feet thick and show evidence of water bedding, the stones being distributed in horizontal lines or beds at definite levels in the deposit. This is probably not a direct deposit from the ice sheet, but may have been laid down by drainage from the ice sheet, as it is near the limits of glaciation. The stones range in size from boulders 2 feet in diameter down to pebbles, and show considerable rounding by stream action. The discussion of glacial drainage on the Schuylkill appears below.

JERSEYAN TILL IN NEW JERSEY

The present writer examined a number of exposures of the Jerseyan till in New Jersey and found that it has on the whole a more clearly defined glacial character than that in much of the area of this early glaciation in eastern Pennsylvania. Many of the rocks in it are evidently derived from formations whose nearest outcrops are at considerable distance, and in the direction from which the ice came.

There are good exposures of the till in the southernmost areas of the deposit, as mapped by the New Jersey Geological Survey. In ravines north of Somerville that drain to Peters Brook are several exposures of deeply weathered till, 10 to 15 feet deep, that do not reach the rock. The granite and gneiss pebbles in the till show a weathered rind and an advanced state of decay. No pebbles seen display as fresh an aspect as some of the granite and gneiss pebbles in the Illinoian drift. Many of the red and purple quartzite pebbles also have a thin weathered rind, whereas those in the Illinoian drift lack such evidence of age.

North of Raritan, gravel pits have been opened in a deposit classed by Kümmel as Pensauken gravel. Over part of the deposit there is a thin sheet of very deeply weathered clayey till. If the identification as Pensauken is correct, it makes that deposit antedate the Jerseyan glacial stage. The gravel may, however, prove to be a reworked Bridgeton gravel. The surface altitude is 150 to 156 feet above sea level, which is a little above the altitude of the Pensauken deposit in the broad belt extending from Raritan Bay across New Jersey to Trenton. The question of the age and relations of the Pensauken formation is discussed below.

About a mile south of Whitehouse a road cut across a ridge exposes 12 to 15 feet of deeply weathered till above a red shale. This deposit runs out within a short distance each way from the crest of the ridge, showing that it has suffered much erosion and is preserved only where erosion has been at a minimum. Between Whitehouse and Clinton in the vicinity of Potterstown, Lebanon, and Annandale, the drift is exposed on similar summits or divides between drainage lines, and generally is only 8 or 10 feet thick.

In the cut along the Central Railroad of New Jersey northwest of Highbridge the drift ranges in thickness from 10 feet to about 30 feet. It includes much partly assorted coarse drift, with boulders and cobbles in definite horizontal beds. But in places there is a clayey till without bedding planes. A striated boulder about one foot in diameter was found in the till near the west end of the cut. This deposit includes various kinds of rock from widely separated formations, and is on the whole about the best exhibit of the Jerseyan drift seen in the State.

The exposure of Jerseyan drift at Pattenburg is in a railroad cut east of the station. The deposit is only 10 to 15 feet thick, and rests upon a red shale. On account of the incorporation of this shale in the drift its color is exceptionally red. The rocks in the drift show considerable variety, and all are deeply weathered.

In places the Jerseyan drift includes assorted beds with disturbed aspect, as if shoved and crumpled by glacial movement over them. A gravel pit about a mile southeast of Far Hills, on the south side of the outlet of glacial Lake Passaic, shows disturbance of this sort. The altitude is about 40 feet higher than the lake outlet, so the deposit is entirely independent of lake action. The gravel is exposed to a depth of 8 feet, and is very deeply weathered throughout, as is consistent with its great age.

PLANES OF DEPOSITION ON SCHUYLKILL RIVER

On the lower course of Schuylkill River and its immediate borders, in the Norristown, Germantown, and Philadelphia quadrangles, as indicated on maps in the Philadelphia folio,[1] there are deposits of sand and gravel at various altitudes up to 460 feet A. T. The highest deposits, called Bryn Mawr, are interpreted to be of Tertiary age. Deposits referred to the Quaternary reach about 300 feet above sea level and are abundant at about 100 feet and lower altitudes. Deposits known as Pensauken are extensively preserved at altitudes between 100 and 120 feet in the vicinity of Philadelphia. The type locality is on Pensauken Creek, which enters Delaware River from the east just above Philadelphia. A higher gravel, called the Bridgeton, is well preserved on the New Jersey side of the Delaware, but has not been mapped under this name on the Pennsylvania side. It is probably represented in some of the Quaternary deposits preserved near the mouth of the Schuylkill.

An attempt was made recently by M. R. Campbell to trace Tertiary and Quaternary gravel deposits up the valley from near the mouth of the Schuylkill. A brief statement[2] of the results of this study, together with the results of his studies on the Susquehanna and Potomac valleys appeared in 1929. In a series of profile sections along each of these valleys the Bryn Mawr formation is represented to rise for a few miles up each valley, and then show a decline for some distance farther, followed by a rise still farther up the valleys. There is thus an anticline with a syncline back of it. On the Schuylkill the anticline is made to pass over Bryn Mawr and cross the river near Norristown, while the axis of the syncline is made to cross the river near Reading. As thus interpreted the altitude of the Bryn Mawr is 100 feet lower at Reading than at Bryn Mawr. The evidence in support of this deformation is very fragmentary on the Schuylkill, there being no remnants of the formation noted between Bryn Mawr and Reading.

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[1] Folio 162, U. S. Geol. Survey.

[2] Campbell, M. R., Late geologic deformation of the Appalachian Piedmont as determined by river gravels: Nat. Acad. Sci., Proc., vol. 15, no. 2, pp. 156-161, Feb. 15, 1929.

This is largely due to the general reduction of the country along the Schuylkill to a level below the plane of the Bryn Mawr. The presence of a syncline on the Schuylkill is thus made to depend upon a single occurrence of gravel, that at Reading. Above Reading a fluvial deposit on a well-defined terrace, 80 to 100 feet above the river, is interpreted by Campbell to be a continuation of the Bryn Mawr formation, though it is probably of much later age, as indicated below.

Campbell's profile section on the Schuylkill represents two gravel beds at lower levels than the Bryn Mawr. The upper one, called the Brandywine, is shown to extend from Norristown nearly up to Reading, while the lower one is shown from Norristown nearly to Pottstown, and placed 60 to 80 feet below the Brandywine. Neither of these gravels was traced down the Schuylkill valley far enough to show their relations to the Pensauken and Bridgeton gravels of the Delaware valley. It is suggested that the gravel below the Brandywine may be of glacial age. The Brandywine gravel is thought to show a descent down the valley as far as Pottstown, but to be practically level at 200 to 220 feet below that point. The lower gravel is thought to hold a uniform altitude of about 140 feet for the entire distance examined, from near Pottstown to Norristown.

The present writer's studies of the Schuylkill valley were confined to the part of the valley above Reading. As indicated in the discussion of the pre-Illinoian drift, the headwaters of Little Schuylkill River were covered by the ice sheet, and the ice reached to, if not a little beyond, the divide at the head of northern tributaries of the Schuylkill River. The conditions thus seem favorable for the use of the Schuylkill valley as a line of discharge for glacial waters. There may have been a temporary partial blocking of the part of the valley south of Blue Mountain, if the ice had the extent there that Williams supposed. The part below Reading would have had no obstruction to the discharge of glacial waters.

The terrace at Brockton, near the head of the Schuylkill, was the only one found in this headwater district with deposits suggesting glacial drainage. This deposition occurred when the river was flowing at a level 40 to 50 feet above its present level. The deepening seems moderate if the terrace dates back to early Pleistocene time. In the portion of the valley between Pottsville and Hamburg, where several mountain ridges are cut by the river, terraces suitable to retain deposits of gravel are almost entirely wanting, and any deposits as remote as the early Pleistocene glaciation are likely to be reduced to scattered pebbles. Better conditions are found in the part of the valley between Blue Mountain and South Mountain, where the stream traverses the slate hills and limestone lowland. Definite terrace remnants carrying fluvial deposits are found at a level about 80 feet above the stream. The terrace is better preserved in the slate area, from near Hamburg to Leesport, than in the limestone lowland between Leesport and Reading, for the limestone has been given an uneven surface by solution and underground drainage. The deposits on the terrace above Shoemakersville are sandy gravel, in places several feet in depth. Exposures along the Belt Line Railroad at Glenside, opposite the north part of Reading, show a clayey alluvium 20 feet or more in thickness, with boulders and cobbles scattered through it. Exposures in the Pennsylvania Railroad cuts north of Millmont Junction, near the southern limits of Reading, show boulders and cobbles in a sandy matrix.

This terrace and its deposits seem likely to connect with the gravel deposits farther down the valley, classed by Campbell as Brandywine, and to be continued in the Brandywine plane of his profile as far as Pottstown. The following table of elevations sets forth the relation of the terraces to the present stream in the interval between Shoemakersville and Pottstown. The striking parallelism in this part contrasts so markedly with the divergence in the part below Pottstown, as interpreted by Campbell, that there seems need for reexamination of that part of the valley.

Altitudes of terrace and Schuylkill River, in feet above sea level:

	Terrace	*River*	*Difference*
Shoemakersville	380	300	80
Mohrsville	365	280	85
Tuckerton	340	250	90
Glenside	280	200	80
Millmont Junction	265	185	80
Guckerville	250	150	100
Douglasville	230	130	100
Pottstown	220	120	100

In the southwest part of the Hamburg quadrangle, above Shoemakersville, there are scattered cobblestones and boulders up to a height of about 40 feet above the level of the fluvial deposits on the terrace, or 440 feet above the sea level. The stones above 400 feet are strewn over a slope as if lodged there at a time of flooded conditions, and are not accompanied by such deposits of sand and gravel as appear on the terrace. Whether the flooded condition was a temporary one, caused by some blocking of the valley below there, or instead the stones were laid down in a more remote period than the fluvial deposits on the terrace remains unsettled. Their deposition seems likely to have been less remote than the Bryn Mawr formation for there has been very little breaking down of the surface of the slope on which they lie.

GRAVEL DEPOSITS ON DELAWARE RIVER

The interpretation of gravel deposits on the Delaware Valley is complicated by the fact that the Triassic formations that border much of the valley between the glacial boundary and Trenton include conglomerates, which upon weathering yield waterworn stones that are difficult to distinguish from cobblestones brought down the valley by streams. The occurrence of cobblestones on rock shelves on the valley borders may thus have no connection with the glacial drainage. There is the further complication that the Illinoian drift reached about the same limit on the Delaware as the pre-Illinoian. It thus becomes necessary to distinguish the Illinoian valley train from any earlier one. But the field investigation failed to bring to light a sufficiently definite valley train below the glacial boundary to be traceable with certainty, or to be clearly distinguished from the pebbles that have weathered out from the local conglomerate.

For a few miles above Trenton, as far as Raven Rock, pebbly deposits were found on rock shelves that seem to be the product of stream action. At Raven Rock they are at an altitude of 200 feet, or about 130 feet above the river. Back of New Hope, Pennsylvania, a terrace is strewn with pebbles at 140 to 160 feet above tide. At Titusville the upper limit of pebbly deposits is about 140 feet, and at Trenton about 120 feet. The river comes into the Coastal Plain just above Trenton and enters the broad belt of Pensauken gravel that comes in from the east and extends down the river past Philadelphia. The deposits just noted, between Raven Rock and Trenton, appear to correlate with the Pensauken formation. This formation probably had feeders from the north on the Delaware, Millstone, and Raritan rivers, but none of them carries a conspicuous valley train, and the development of the formation seems to have been largely independent of them.

MILLSTONE RIVER ONCE FLOWED SOUTH

Millstone River, which now flows northward into Raritan River near Somerville, has had a southward discharge past Kingston into the plain covered with Pensauken gravel near Princeton. Deposits in its valley at Kingston show clearly the bedding of a southward-flowing stream. They are built up to an altitude of nearly 130 feet, and thus correspond in level with the Pensauken level. The deposit includes coarse cobblestones and a few larger stones. Blocks of indurated sandstone, 18 to 20 inches in diameter and several inches thick, are thought by Kümmel to have been derived, perhaps, from the Hardyston quartzite far to the north. From the place where the stream passes from the old rock formations to the Coastal Plain series near Princeton coarse cobblestones 8 or 10 inches in diameter have been carried several miles southwest from Millstone River. These seem likely to have been brought out of the Millstone Valley. Likewise, material of exceptional coarseness is found on the borders of the Delaware at the level of the Pensauken formation below its entrance on the Coastal Plain. Scattered boulders occur on the Pensauken formation southwest of Princeton, and also along the Delaware above Trenton, but their mode of deposition is not clear.

GRAVEL DEPOSITS ON THE RARITAN

There seems to be no definite valley train of gravel on Raritan River, where it follows the border of the Jerseyan drift, above Somerville, nor down the valley from Somerville to the plain covered by the Pensauken formation. In places within its drainage area, as a mile east of Somerville and at the gravel pits north of Raritan, gravel occurs that has been referred by Kümmel to the Pensauken. Gravel of this sort has also been noted in North Plainfield, on the west side of Green Brook, a north tributary of Raritan River, at an altitude of 130 to 140 feet. This gravel is just outside the border of the Wisconsin drift, but it is made up almost entirely of quartz pebbles, and thus differs from surrounding Wisconsin outwash, which is made up largely of rocks of other kinds.

THE PENSAUKEN FORMATION

The origin, mode of deposition, and place in the Pleistocene series of the Pensauken formation have been the source of considerable speculation. Although it is made up largely of quartz pebbles that have been reworked and redeposited from epoch to epoch in Tertiary and early Quaternary time, it includes also a considerable percentage of rocks of other kinds derived from formations which crop out in northern New Jersey and adjacent districts. The rocks all show considerable water wear, and thus seem to have been carried for some distance in streams or currents.

The formation is present in a broad belt extending across New Jersey from Raritan Bay to the Delaware Valley, and then down that valley to the borders of Delaware Bay. In the northern part of the belt some of the rocks present have been derived from formations to the north, and there is a notable amount of arkose mixed in with the quartz pebbles. On the south border the arkose is absent or inconspicuous, and the deposit seems to have been derived from the part of the Coastal Plain formations to the south and east.

The Pensauken formation apparently lies in a broad shallow trough excavated in an earlier formation which, in the New Jersey reports, carries the name Bridgeton, and which is widespread in southern New Jersey. The age of the Pensauken compared with the Bridgeton is measured by the amount of excavation exhibited by this shallow trough. So far as the state of weathering in the two formations is concerned, there is no striking difference, for both are very deeply weathered. The Bridgeton as now preserved seems to be almost if not entirely restricted to the southeast side of this trough. It has not been clearly identified on the north and west sides. But it carries rocks that are derived from formations in northern New Jersey and adjacent districts, and it contains arkose like the Pensauken. Among the rocks found in both formations are boulders and cobbles of red quartzite, such as are present in the Medina and Clinton formations, and pale quartzites, perhaps derived from the Hardyston quartzite. Some boulders are 2 to 3 feet in diameter, a size which seems to call for rafting on ice cakes, if not for transportation by an ice sheet. In either case a rather cold climate seems called for, such as prevailed in Pleistocene glacial stages, and inconsistent with the prevailing warmth of the Tertiary.

The altitude of the Pensauken formation in the belt that leads across New Jersey from Raritan Bay to the Delaware River is mainly between 120 and 140 feet. On part of its southeast border it reaches 150 feet. Its base ranges from 100 feet or more down to 15 or 20 feet above sea level, but in this belt that crosses New Jersey the base is commonly between 70 and 100 feet. The surface or upper limit declines gradually down the Delaware Valley, and is not far from 100 feet in the part southeast of Camden. The base in Camden and Philadelphia is about down to sea level, and in places the Pensauken is found under the Cape May formation, of late Pleistocene age. In that district the Bridgeton has a base at about 120 feet, beneath the remnants nearest the Delaware Valley. Its upper surface on the divide between the Delaware and streams leading southeastward to the Atlantic is at 180 to 190 feet. But data as to the altitude of its base there are not at hand.

The Pensauken formation displays remarkable differences in amount of erosion. It is preserved only in patches and narrow strips for some miles back from the Delaware near Trenton, but is nearly intact in wide areas north and west of Jamesburg, where the surface is characterized by basins and swampy depressions that seem to be unaffected by post-Pensauken drainage. The origin of these basins has not been clearly determined. Possibly they have been developed to some degree by underground drainage. If so they may have required a relatively long period for development, in harmony with that involved in the great erosion displayed by other parts of the formation. Generally the formation as preserved is less than 10 feet thick, but gravel pits in it near Jamesburg and Fresh Ponds have a depth of 35 to 40 feet without reaching the bottom of the deposit, and a similar depth is exposed in railroad cuts west of South River and near Milltown.

On the whole the formation shows a degree of weathering and erosion markedly greater than the Illinoian drift has experienced, and more in keeping with that of the Jerseyan drift. This inference seems sustained by its relation to the Jerseyan till in the pits north of Raritan, noted above.

A recent attempt to interpret the Pensauken formation has been made by Marius R. Campbell and Florence Bascom.[1] They refer it to an ancient system of drainage, embracing the Hudson and Delaware which are thought to have united near Bound Brook. The present Delaware is west of the old river, and it seems to have been a very minor contributor. They postulate considerable warping that produced the trough in which the deposit lies.

EARLIEST QUATERNARY DEPOSITS

There seems little question that the Bridgeton formation falls in the Quaternary series. There is also a strong probability that it is older than the Jerseyan drift. If it was deposited in a glacial stage, as is suggested by the large number of coarse pebbles and boulders brought in from the north, the drift with which it should be correlated has not been definitely recognized. It may have been reduced to scattered boulders of resistant rocks, the till having beeen entirely washed away.

A pebbly deposit that appears to be older than the Bridgeton, and which carries a variety of rocks brought in from the north was noted about 2 miles east of Rocky Hill, N. J., on the east side of Millstone Valley at an altitude of 280 to 320 feet. It includes stones as much as 6 inches in diameter, some being of red quartzite, and differs from neighboring Cretaceous gravel deposits in carrying these rocks of northern derivation.

Deposits showing a similar variety of rocks were noted in gravel pits at Broomall, Pa., a few miles west of Philadelphia, at an altitude of 360 to 380 feet. These were examined in company with Dr. Florence Bascom, who considered them of later age than the Bryn Mawr formation, and probably referable to the Brandywine. The variety of rocks is greater than is found in the Bryn Mawr formation.

These deposits near Rocky Hill and Broomall probably stand near the border line between the Tertiary and Quaternary. The knowledge of these deposits seems as yet too meager to justify definite correlations.

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[1] Campbell, M. R. and Bascom, F., Origin and structure of the Pensauken gravel: Am. Jour. Sci., 5th ser., vol. 26, pp. 300-318, 1933.

PRE-WISCONSIN DRIFTS AND ASSOCIATED DEPOSITS IN NORTHWESTERN PENNSYLVANIA

INTRODUCTION

This report sets forth the results of studies of surface features in western Pennsylvania which are referable to pre-Wisconsin stages of glaciation. An earlier report[1] gave principal attention to features of the Wisconsin drift and reference may be made to it for their description. The more recent studies, carried on in the field seasons of 1925, 1926, and 1929, are part of a wider study embracing a considerable part of West Virginia on the border of the Ohio River, and the part of Ohio outside the limits of the Illinoian and Wisconsin drifts. Topographic maps with 20 foot contour interval have been available for nearly the entire area covered by these recent studies. From these maps the altitudes and slopes of the glacial gravels and other deposits in the valleys can be determined with some precision. The maps also serve to bring out remnants of a Tertiary peneplane, and show its present slopes. The course of the main late Tertiary drainage lines can be determined roughly, and those of early Quaternary age more precisely traced across these maps.

That the present courses of drainage depart widely from those of early Quaternary time has been recognized by geologists for some 50 years, and the subject was discussed at some length by the present writer in the above named report. The later studies have brought to light evidence that some of the changes antedated the time of the general enlargement of the Ohio drainage by the accession of drainage that had been tributary to the Lake Erie Basin. These matters will be touched upon only briefly here as their discussion falls naturally in the more comprehensive report embracing parts of Ohio and West Virginia as well as western Pennsylvania.[2]

Several county and district reports by J. F. Carll, J. J. Stevenson, and I. C. White, published by the Second Pennsylvania Geological Survey, deal mainly with the rock formations of western Pennsylvania and their included products of commercial value, but they also give attention to the surface features and deposits. The same is the case with bulletins and geologic folios of the U. S. Geological Survey, and with reports on the New Castle and Pittsburgh quadrangles by the present Pennsylvania Geological Survey. Papers by E. H. Williams, Jr., G. F. Wright, P. Max Foshay, R. R. Hice, and J. W. Spencer, published in scientific journals, have brought out results of their studies of glacial and drainage features in this region. A paper on the Harrisburg peneplane as developed in western Pennsylvania was prepared by M. R. Campbell,[3] who was also a leading contributor to the geologic folios.

PREGLACIAL DRAINAGE

PROBABLE LATE TERTIARY DRAINAGE

The topographic maps, as well as the field observations, indicate the presence in western Pennsylvania and northeastern Ohio of a somewhat lower tract along the Monongahela, upper Ohio, and Beaver drainage to Grand River and Lake Erie basins than in bordering districts to the west and northeast. In this lower tract the Tertiary peneplane level appears to be between 1,200 and 1,300 feet in western Pennsylvania, but it falls below 1,200 feet in the Youngstown, Ohio, quadrangle and continues descending through the Grand River basin to the Lake Erie Basin. This low tract in all probability carried the main drainage of this region in late Tertiary time. It is here termed the Monongahela-Beaver drainage.

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[1] U. S. Geol. Survey, Monograph XLI, 1902.

[2] This report will probably be issued as a Professional Paper of the U. S. Geological Survey.

[3] Campbell, M. R., Geographic development of northern Pennsylvania and southern New York: Geol. Soc. America, Bull. vol. 14, pp. 277-296, 1903.

Between the Monongahela Valley and the part of the Ohio along the Panhandle of West Virginia there is a somewhat higher tract, standing above 1,400 feet in southwestern Pennsylvania and the south part of the Panhandle, but descending northward in the reverse direction of the present course of the Ohio River. There is a slight rise both to the east and west of the Ohio which seems to indicate that there was a minor drainage line following about the course of the present Ohio (reversed) northward from the vicinity of New Martinsville, West Virginia, to the mouth of the Little Beaver and thence to the Monongahela-Beaver along or near the line of Ohio and Pennsylvania. This is here termed the upper Ohio-Beaver drainage.

To the northeast from the Monongahela-Beaver depression there is a gradual rise across northwestern Pennsylvania into southwestern New York, where the peneplane appears to reach an altitude of about 2,000 feet. This district probably had some drainage southwestward to the Monongahela-Beaver, but from the north part of western Pennsylvania the drainage probably was northwestward directly into the Erie Basin.

The peneplane probably was not much above sea level in this region when reduced to its lowest condition, though the position of the sea coast of that time in relation to these drainage lines is not as yet determined. There evidently has been much greater uplift in the northern part of western Pennsylvania than in the southern part. It is not so evident that the rise west from the Monongahela Valley is due to greater uplift there, or instead is due to the distance from the main drainage line.

DRAINAGE AT BEGINNING OF GLACIAL EPOCH

The Monongahela-Beaver drainage appears to have been continued into the Erie Basin down to the time of the earliest glacial invasion, and to have reached a level in western Pennsylvania within 200 to 300 feet of the present stream levels. A condition of relative stability appears to have been reached at a time considerably earlier than the ice invasion, as a result of which the valley slopes had become toned down and the valley floors had become moderately wide.

The Monongahela-Beaver drainage (Fig. 35) received the drainage of the present Allegheny River only from as far up as the Clarion River, the part above being more directly tributary to the Erie Basin. The Clarion, and other tributaries nearer the mouth of the Allegheny, have erosion features in harmony with the Monongahela-Beaver system, with a well defined valley floor about 200 feet above the present streams at their junction with the Allegheny River.

The portion of the Allegheny River above the Clarion is an accession caused by the ice invasion, which displaced or reversed drainage lines

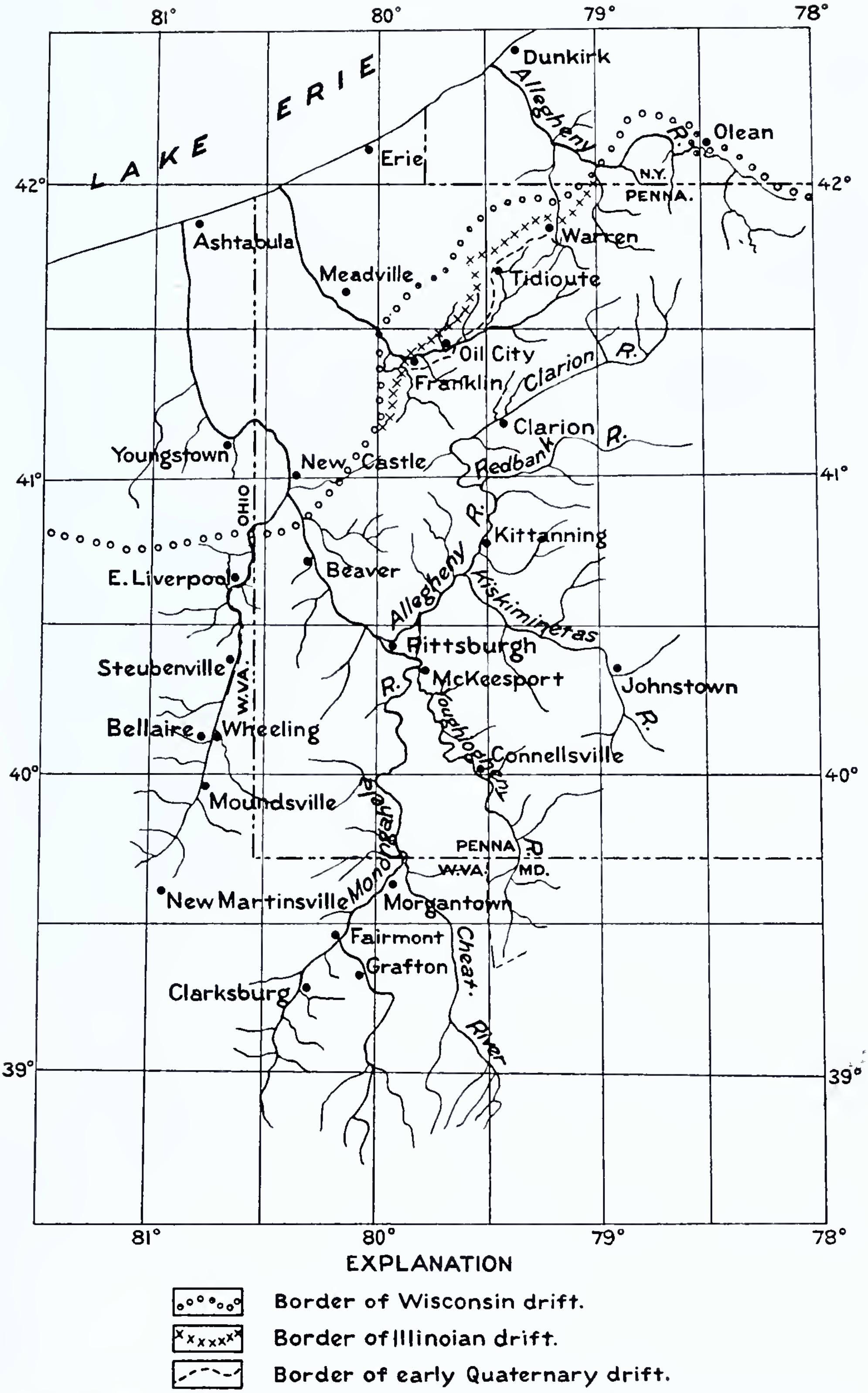

Figure 35. Preglacial drainage of upper Ohio drainage system in relation to glaciation.

that had led northwestward directly into the Erie Basin, and turned them into the lower Allegheny drainage system. Some of these valleys had been cut down to much lower levels than had been reached by the lower Allegheny system. Parts of the valley floors developed by this northwestward drainage are below the level of the present streams, and have the toned down slopes to and below present stream level. There were two main lines of northwestward drainage, one being known as the upper Allegheny, which included the present Allegheny drainage as far down as eastern Warren County, Pennsylvania, and had its discharge across southwestern New York. The other, known as the middle Allegheny, embraced the part of the present Allegheny between southwestern Warren County and the old divide near the mouth of the Clarion. There is some uncertainty as to the line of discharge for the Brokenstraw and Conewango valleys, and a small section of the Allegheny near Warren, Pennsylvania, though the most probable course seems to be northward through the Conewango Valley, to connect with the upper Allegheny in southwestern New York. There is similar uncertainty as to the courses of drainage to the Erie Basin from the part of Oil Creek above Titusville, and the part of French Creek above Meadville, Pennsylvania. The valley floors in these cases are deeply buried beneath the present streams, and borings are not sufficiently well distributed to give satisfactory data as to the slope of the floors. The present state of knowledge as to the courses of the preglacial drainage lines is set forth in Figure 35.

It has been commonly held that the northward drainage through the Beaver Valley to the Erie Basin was permanently reversed at the earliest glacial invasion. This interpretation, however, seems open to question. Certain features suggest that northward flow was resumed after this early ice invasion and continued down to the time of the Illinoian ice invasion. This matter can be better treated after the glacial drainage features have been discussed (see p. 101). The deep trenching of the fluvial planes in much of western Pennsylvania seems to have followed the Illinoian glaciation. The enlargement of the Allegheny probably took place at the earlier ice invasion; but the stream work in the part below the mouth of the Clarion seems to have been mainly a widening process down to the Illinoian stage, and the valleys were but little deeper than at the advent of the first ice invasion. Abandoned oxbows of a stream smaller than the present Allegheny, and probably opened by the Clarion—lower Allegheny preglacial drainage, had been cut to within about 200 feet of the level of the river before their abandonment. One of these abandoned oxbows is east of the Allegheny opposite Parkers Landing, and another is found in the south part of the New Kensington quadrangle, on the west side of the Allegheny. Its size compared with the present Allegheny is shown in Figure 38. Both have a rock floor about as low as the rock floor under the Illinoian gravel in neighboring parts of the Allegheny Valley, but their width is much less than that of the Allegheny Valley.

EARLY QUATERNARY GLACIAL DEPOSITS

The deposits of early glacial age are very scanty in northwestern Pennsylvania, and chiefly in the form of gravel, deposited along lines of glacial drainage. The most conspicuous deposits are in the old Tionesta Valley, in the vicinity of Clarendon, in Warren County. There appears to have been an extension of ice into the north end of this valley as far as Clarendon, and the ice held its position there long enough for its outwash to be built up to a level about 300 feet above the old valley floor, and thus cause a permanent diversion of the Tionesta drainage.

Deposit near Clarendon, Warren County. The part of the old valley between Clarendon and the Allegheny Valley carries a deposit of stony drift that is the nearest approach to till of any early glacial deposit noted in this region. The ice border seems to have stood a long time at Clarendon, and then melted back gradually, leaving the stony deposit as it melted. This stony deposit is not built up to the level of the outwash gravel train, but coats the slope between the head of the gravel train and the Allegheny Valley. From descriptions given by oil well drillers the filling in the old Tionesta Valley seems to be mainly clay, as is to be expected because of the ponded condition produced by the blocking of the northward drainage by the advancing ice sheet. It was not until the deposits in front of the ice had been built up as high as the col near Sheffield, across which the Tionesta was diverted, that conditions became favorable for the transportation of sand and gravel into the outlying part of the valley. This seems to have begun when the filling reached about 1,400 feet above sea level. In a pit north of Tionesta Creek in the west part of Clarendon there is sand from 1,400 to about 1,440 feet. Gravel sets in at the top of the sand, and this was built up to about 1,500 feet at the head of the valley train. It slopes down the valley, its upper limit at Weldbank 1½ miles below Clarendon being below the 1,480-foot contour.

A gravel deposit is exposed in a pit near the dam on Tionesta Creek in old Clarendon at an altitude a little below 1,400 feet which has fresher aspect than that of the gravel in the pit above noted. This may be a reworked part of the valley train, where it has been trenched by Tionesta Creek, and thus let down below its original level. Most of the valley train has been removed by Tionesta Creek along the entire course of the stream, and remnants are found at the full level only in protected places, such as the lee of projecting points like that opposite Weldbank. The amount of work done by this small drainage line since the deposition of the outwash gravel is so great as to require a period of erosion dating back into early Quaternary time.

Deposit near Warren. A gravelly deposit of probable early glacial age is found in the northeast part of Warren on the north side of Indian Hollow, an eastern tributary of Conewango Creek. It lies on a slope above the Illinoian gravel terrace. The terrace is nearly 1,400 feet and this gravel reaches an altitude of fully 1,460 feet. It carries deeply weathered granite pebbles, some of which are 5 or 6 inches in diameter. Large blocks of local sandstone are strewn over this slope and similar blocks are struck in wells drilled for oil. This gravelly deposit increases in thickness toward the brow of the Conewango bluff, the slope of the rock floor being greater than that of the surface deposit. The rock surface falls from 1,450 feet to about 1,400 feet in a space of a quarter of a mile beneath the gravelly slope. There is then an abrupt drop to 1,125 feet or less on the valley floor. A pit opened in the east bluff of Conewango Creek just north of Indian Hollow has a predominance of sand in the lower part. Above this are gravel beds with southward dip, partially cemented with lime, and presenting a rather fresh aspect, the granite and limestone pebbles being but slightly etched. These gravel beds are capped with a deposit of coarse cobble and rubble, horizontally bedded and about 10 feet thick. This coarse capping seems to be connected with the drainage from the Illinoian ice sheet, whose border was in that vicinity. It fits in with extensive terraces in East Warren that were built up to about 1,380 feet in the Illinoian stage. The underlying dipping beds probably are also of Illinoian age. Possibly the sandy beds below are pre-Illinoian. It is in these beds that E. H. Williams found a nugget of native copper, which he thought may have come from the Lake Superior region.[1] The Illinoian movement into northwestern Pennsylvania appears to have been from the northeast instead of from the northwest, the direction of the Lake Superior copper region. If this is the source of the copper it will be indicative of an earlier ice movement from the northwest. The fact that copper is widely distributed over Ohio lends strength to Williams interpretation. The sand deposits in which the copper nugget was found are not markedly more weathered than the overlying gravel, and thus do not bring decisive evidence of pre-Illinoian age.

Williams has put the limits of glaciation south of the Allegheny Valley below Warren. In evidence of this he cited a deposit of red silt including cobblestones 3 miles southeast of the river, opposite Cobham, at an altitude of 1,700 feet, and others south of Tidioute, which he classed as drift, though he gave no information as to the kind of rocks.[2]

Evidence that the ice sheet came nearly to the Allegheny Valley in the southwest part of the Tidioute quadrangle was noted by R. M. Leggette of the U. S. Geological Survey,[3] who found a granite boulder 3 feet in diameter half a mile south of Hunter Run school, at an altitude of about 1,350 feet, it being near a U. S. G. S. bench 1,348 feet. It is deeply embedded in the soil and evidently *in situ*. Residents of that district have also reported the occurrence of scattered boulders along the west side of the Allegheny in the vicinity of Tidioute.

Deposit near Tidioute. On both sides of the Allegheny River in the vicinity of Tidioute are deposits of glacial gravel that seem to be an outwash from an early Quaternary ice sheet. The deposits have an upper limit just below the 1,400-foot contour, and have a flat surface. They appear to have been built up by stream action. They contain numerous granite and greenstone pebbles of Canadian derivation, all deeply weathered. The largest granite noted was about 10 inches in diameter, but the erratic pebbles are generally less than 4 inches. It seems probable from their coarseness that these deposits are near the head of a valley train connecting with the ice border, and that the Allegheny Valley was covered by the ice sheet about to Cobham.

Deposit near Oil City. The limits of the early Quaternary glaciation were probably near the Allegheny Valley as far down as Franklin, and possibly as far as Kennerdell. In the vicinity of Oil City and Franklin the ice seems to have extended slightly beyond the valley. Williams reported finding red granite in field cullings about 1½ miles south of the Allegheny near South Oil City at altitudes above 1,460 feet.[1] The writer has noted cobblestones up to a similar altitude on the south side of the valley farther west.

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[1] Pennsylvania glaciation, first phase, pp. 85-86, fig. 43, 1917.

[2] Op. cit. p. 101.

[3] Personal communication.

In the vicinity of Oil City there are features at about 1,300 feet that seem referable to glacial drainage. They are about 50 feet higher than a well-defined gravel terrace of probable Illinoian age, and may pertain to a pre-Illinoian glaciation. In the south part of Grove Hill cemetery, near the eastern limits of Oil City, a gravel deposit standing above the 1,280-foot contour carries quartzite and indurated sandstone pebbles of several kinds, but apparently no granite or other rocks of Canadian derivation. The gravel has a more deeply weathered appearance than that of the Illinoian terraces and has a loamy rather than sandy matrix.

In South Oil City there is a terrace at about 1,280 feet, carrying scattered pebbles, which seems to correlate with the gravel deposit at Grove Hill cemetery. A pass at about 1,280 feet at the head of a north branch of Lower Two Mile Run, just below South Oil City, may have been a spillway for glacial waters while the Allegheny Valley was covered by ice below Oil City. The pass has a flat floor about 30 rods wide, and is nearly level lengthwise for half a mile, as shown by the 1,280-foot contours. There is no gravel in this pass, but this is a natural condition if there was ponded water north of the pass in the lower country between it and the Allegheny River. The probable preglacial drainage of the Oil City-Franklin region compared with the present drainage is shown in Figure 36.

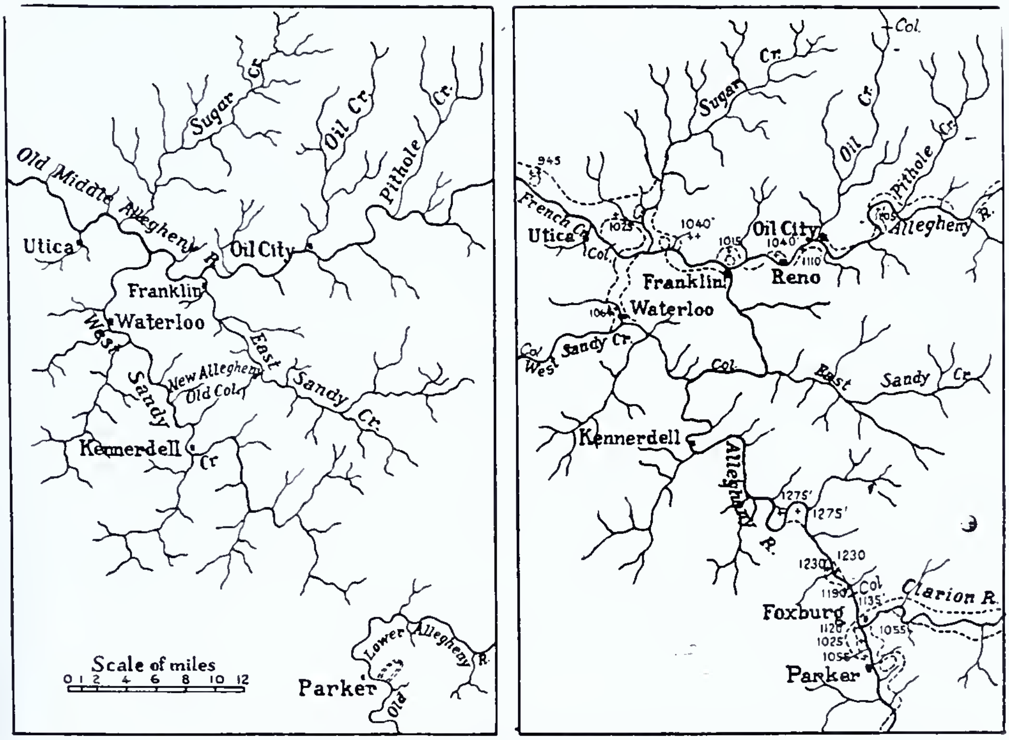

Figure 36. Probable preglacial drainage in the Oil City-Franklin region compared with the present drainage.

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[1] Op. cit. p. 101.

Erratic pebbles. The present writer has seen no boulders or erratic pebbles on uplands outside the Illinoian drift border south of Venango County. Williams noted ''foreign rocks,'' black gneiss and basalt pebbles, between Foxburg and St. Petersburg at nearly 1,320 feet, and he found that coal flakes from a neighboring outcrop were carried up to a higher elevation than the outcrop. Inasmuch as these pebbles appear to have been noted along a highway, where gravel and coal may have been hauled, there is some uncertainty of their being deposited there by the ice sheet, and especially since no other deposits of glacial derivation have been noted on uplands in that vicinity.

A most remarkable instance of the occurrence of erratic pebbles in western Pennsylvania is a bed of such pebbles exposed in a gas pipe line trench in Chartiers Creek valley near the northern limits of Washington, reported by I. C. White, who examined them on the ground.[1] The altitude is 1,050 feet, or somewhat higher than the glacial gravel filling on the Ohio at the mouth of Chartiers Creek. But White suggested that the pebbles were rafted on ice in ponded water extending up to this locality and bringing the glacial pebbles from the Ohio Valley. This seemed to him a more probable occurrence than an extension of the ice sheet so far south. In the same paper White called attention to the occurrence of erratic pebbles on the border of the Ohio Valley near Sewickley, Pa. at an altitude of about 1,250 feet, and near Sistersville, W. Va., at similar high altitude. In these cases the pebbles are found only within about a mile of the river bluff. They are also small, the largest being only about 6 inches in diameter. It seemed to him more probable that they had been carried up from the Ohio Valley by Indians than that the ice sheet reached these localities. The extension of the ice sheet to Sistersville seemed highly improbable. Transportation by Indians does not seem applicable to the pebble bed found near Washington. It thus remains a very puzzling feature.

Gravel that appears to be of early glacial age has been noted at several places along the Allegheny and Ohio valleys outside the recognized limits of glaciation. Its altitude is somewhat higher than that of the Illinoian gravel, and it is more deeply weathered. Reference has already been made to the occurrence of such gravel in the vicinity of Tidioute, and near Clarendon and Warren. In part of the Allegheny Valley, in the Franklin, Hilliards and Foxburg quadrangles, the gravel has not been recognized in distinction from the Illinoian gravel. In the Kittanning quadrangle gravel at higher altitude than the Illinoian has been noted near East Brady, and at the mouth of Redbank Creek. Though no pebbles of glacial derivation were noted in it there is a strong probability that it is the product of glacial drainage, for gravel carrying glacial material has been found below there, in the Freeport quadrangle, at corresponding heights above the Illinoian gravel train. The gravel near East Brady is on the west side of the Allegheny Valley at an altitude of 1,160 to 1,180 feet, and that south of the mouth of Redbank Creek is near the same level. In both localities it is represented as ''older alluvium'' on the map in the Kittanning folio. The upper limit of the Illinoian gravel is about 1,100 feet near East Brady, and 1,080 feet near the mouth of Redbank Creek.

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[1] White, I. C., Rounded boulders at high altitudes along some Appalachian rivers: Am. Jour. Science, 3d ser., vol. 34, p. 377, 1887.

Deposit near Freeport. In the Freeport quadrangle glacial gravel has been noted at several places at levels 40 to 60 feet above the Illinoian gravel train. It reaches the 1,100 foot contour on the east bluff of the Allegheny north of the mouth of Kiskiminetas River, and is above 1,100 feet on the west side of the Allegheny 7 miles farther up stream. In the north part of Freeport, east of Buffalo Creek, it stands above 1,080 feet. It is also above 1,080 feet at a cemetery about 3 miles below Freeport. Deeply weathered granite and other crystalline rocks of glacial derivation were found in the deposit north of the mouth of the Kiskiminetas, and granite pebbles at the cemetery below Freeport. There is thus no uncertainty that these high deposits are to be included in the glacial series. In all these places in the Freeport quadrangle the gravel is composed almost entirely of small pebbles, there being but few over an inch in diameter. They are deeply weathered and have a loamy matrix that is oxidized to a red color. The small remnants of this old gravel are found on rock shelves with an altitude of 1,040 feet or more. The thickness at the cemetery and also north of Freeport is between 20 and 40 feet. It is much less in the other localities. It may not follow that the valley excavation had reached only to 1,040 feet in the vicinity of Freeport at the time this gravel was brought in. On the whole it seems more probable that the gravel overlaps rock shelves on the border of a valley that had been opened to a lower level, perhaps to the level of the rock floor beneath the Illinoian gravel, which is about 940 feet.

Deposits on lower Allegheny River. There are places farther down the Allegheny Valley where pebbles have been noted on its borders at higher altitudes than the Illinoian gravel filling, which probably are connected with the early Quaternary glacial drainage. Thus at the south edge of the New Kensington quadrangle and 1½ miles west of Verona, on the east side of Squaw Run, a flat topped area at 1,040 feet altitude is strewn with deeply weathered, well rounded pebbles of indurated sandstone. The surface of the Illinoian gravel there is about 50 feet lower, being below the 1,000-foot contour.

At Rosedale, south of Verona, near the north edge of the Pittsburgh quadrangle, pebbles, mainly indurated sandstone, occur on the borders of an abandoned oxbow channel at 1,040 feet.

Deposits of rusty, deeply weathered gravel at Valley Camp, on the east bluff of the Allegheny just above New Kensington, whose upper limit is between 1,020 and 1,040 feet, seem likely to be pre-Illinoian, though they are but slightly higher than the Illinoian filling, which is fully 1,000 feet. The degree of oxidation and weathering seems of more significance than the altitude at this place. Gravel deposits that stand above 1,000 feet, and seem from the degree of weathering to be of Illinoian age, are found at several places below New Kensington as far as Bellevue.

A short distance below Pittsburgh, back of Coraopolis on the south side of the Ohio, a deeply weathered glacial gravel, containing granite pebbles, caps a hill at an altitude of 1,000 feet. This deposit seems referable to the early Quaternary rather than the Illinoian stage.

Glacial gravel that appears to be of early Quaternary age is preserved at several places near the mouth of Beaver River, at an altitude about 60 feet above the neighboring Illinoian terraces. Deposits back of Freedom in the eastern edge of the Beaver quadrangle and western edge of the Sewickley are at an elevation of 1,020 feet. Deposits near the Beaver waterworks reservoir, west of the mouth of the Beaver, are between 1,000 and 1,020 feet, and deposits south of the Ohio on Doctor Heights, opposite the mouth of the Beaver, are slightly above 1,000 feet. The upper limit of the Illinoian gravel in that vicinity is about 960 feet. There are also places along the east side of Beaver River between Rochester and New Brighton where a deeply weathered gravel is preserved on narrow rock shelves at 1,000 to 1,020 feet. In all these places near the mouth of Beaver River the pebbles are much more deeply weathered than pebbles of the same kind in the Illinoian gravel.

Immediately below where the Ohio River leaves Pennsylvania, and opposite the mouth of Little Beaver Creek, east of Chester, W. Va., a deeply weathered glacial gravel of probable early Quaternary age is present to fully 1,020 feet. A very deeply weathered granite rock 8 inches in diameter was found in it at an altitude of 990 feet, and red pebbles that appear to be from the Medina formation of western New York at 1,020 feet. This is about 100 feet above the level of the Illinoian gravel in that part of the Ohio Valley.

A deeply weathered glacial gravel has been traced down the Ohio Valley as far as Bellaire, Ohio, and found to have a very slight descent, the top of the deposit at Bellaire being up to 1,000 feet, and the base above 960 feet. Bellaire is 54 miles below the mouth of Little Beaver River, the nearest stream that could have brought glacial gravel into the Ohio Valley. Under the present altitude relations the deposit has a descent of only 20 feet in that distance. The Ohio now falls 40 feet in the same interval, from 660 to 620 feet. The top of this early glacial deposit at Bellaire is thus 380 feet above the low water level of the river. The deposit is well exposed in sand pits south of the mouth of McMahons Creek, in the southeast corner of the St. Clairsville quadrangle. At the base there is a gravel bed 3 to 5 feet thick, in which many of the pebbles are 1 to 2 inches in diameter. The size of the pebbles as well as the relatively slight amount of sand in this bed indicate a current of moderate strength. Above the gravel there is a pebbly sand deposit about 20 feet thick, which has been drawn upon for molding sand. Among the pebbles are granites and other rocks from outside the present watershed of the Ohio, evidently derived from glacial deposits.

ABANDONED EARLY QUATERNARY CHANNELS

OHIO RIVER

From the data given above it appears that the upper Ohio River had, or acquired, southward discharge at the time the early glacial gravel was brought in and that it was flowing at a level fully 350 feet above the present stream in the vicinity of Bellaire and Wheeling while depositing this gravel. It has generally been assumed that the Ohio River has had a continuous southward discharge since that time. There are, however, certain features that are somewhat difficult to adjust to such an interpretation. The most striking of these features are the abandoned oxbow loops of a small drainage line that appear on each side of the Ohio Valley between East Liverpool, Ohio, and the Pennsylvania line (Fig. 37). The one on the north or Ohio side is back of

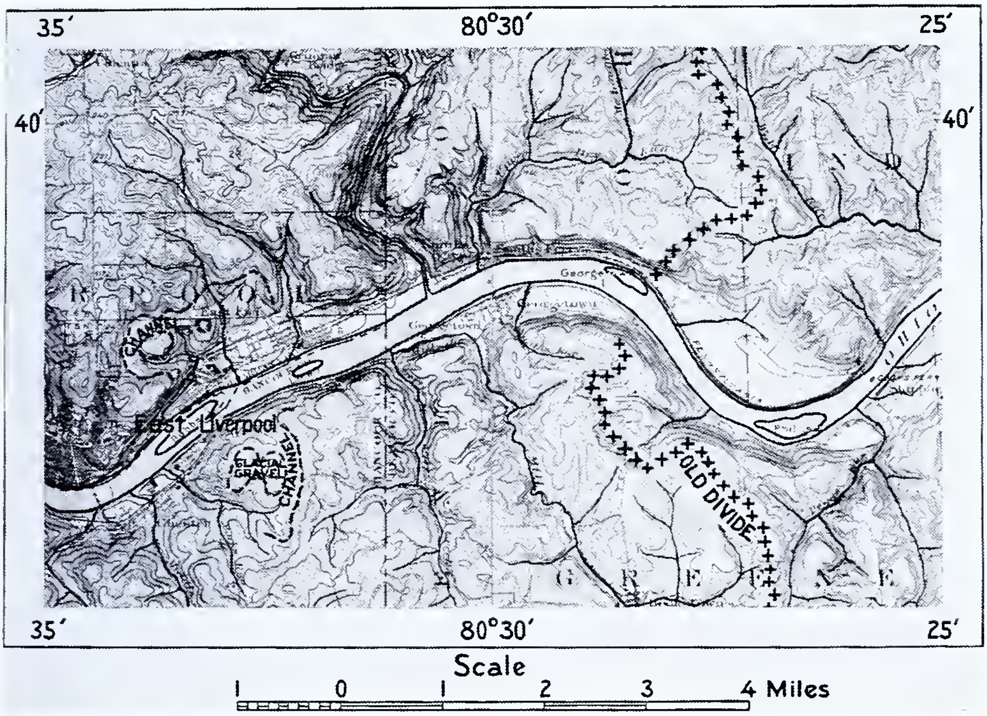

Figure 37. Topographic map showing old divide crossed by Ohio River east of Georgetown, Pennsylvania, and small, winding channels near East Liverpool, Ohio.

East End, and the other a little east of it on the south or West Virginia side is directly east of Chester, W.Va. The bed of the channels is less than a quarter of a mile wide, and it stands about 300 feet above the river, being between 960 and 980 feet above sea level. The channel on the West Virginia side winds around the gravel capped area above noted in which pebbles of glacial derivation occur at 990 and 1,020 feet, and thus has the appearance of being developed after the deposition of the gravel. It evidently is too small a channel to have carried the Ohio River, and thus suggests an interruption of the southward flow of that stream, and a return to a small stream.

This small winding channel is immediately west of what appears to have been a col that is crossed by the present river. The col is located near the eastern limits of Smiths Ferry and Georgetown villages, in the western edge of Pennsylvania, and it separated drainage that led eastward to the Monongahela-Beaver drainage from a small drainage along the Panhandle of West Virginia in the path of the present Ohio which either discharged northward through the valley of Little Beaver Creek, or received that creek and Mill Creek as its headwaters and drained southward (Fig. 37). This small channel thus fits in consistently with the divide near Smiths Ferry if both were preglacial features. But if this was operating in place of the Ohio River after the early glacial gravel was brought in, it is difficult to account for the lowering of the Ohio Valley in that section to the level it appears to have reached at the time of the Illinoian ice invasion. The Illinoian gravel at the mouth of the Beaver as well as at East Liverpool is lower than these small channels near East Liverpool. The gravel is coarse, indicating free drainage below the mouth of the Beaver. We thus have a condition that seems to call for the continuous operation of the Ohio River in this part of its course in the interval between the early Quaternary glaciation and the Illinoian stage. While therefore the general appearance of this little valley is such as to give the impression that it was cut after the first ice invasion there is need for inquiring into the possibilities of its antedating that glaciation.

Studies on the lower Allegheny, as indicated below, have shown that channels similar to these that have oxbow loops preserved on the borders of the valley, are generally filled with gravel for only part of their course, the part adjacent to the main valley, and have a relatively thin clayey deposit outside the limits of the gravel. These channels back of East End, Ohio, and Chester, W. Va., are now preserved in the parts outside the channel made by the Ohio, and to some extent outside the reach of the main current of the river of early glacial time. This seems to be true of the entire channel as preserved on the north side of the river. On the south side the gravel covers the land around which the loop passes and extends down toward the western end of the channel, but leaves the eastern and southern part unfilled. If it can be shown that these parts as well as the channel north of the Ohio Valley stood outside the main current of the glacial stream that flowed down the valley it would ally them with the unfilled oxbow loops on the Allegheny and allow them to antedate the early glacial gravel deposition. It is also possible that gravel at one time filled the part of the loop close to the Ohio Valley and has since been removed by erosion in the very long period that has elapsed since its deposition. In view of these possible contingencies it seems advisable to leave open the question of the bearing these channels have on the history of the Ohio River.

Not only is their relation to the time of the permanent diversion of the Ohio River to its present course somewhat obscure, but so also is the direction of flow of the small stream that made the channels. It is not clearly determined whether the channels were cut by the Little Beaver flowing southward, or by a small stream coming in from the south that had northward discharge through the Little Beaver Valley. There appears to have been at one time a northward drainage from near New Martinsville, W. Va., into this district and thence by the Little Beaver Valley to the Beaver Valley, and these channels, if of preglacial age, seem to be a natural product of that stream. Evidence has been found that the Little Muskingum has captured the headwater part of one of the tributaries of this northward drainage, Opossom Creek, and it is probable that a stream working parallel to the Little Muskingum along the course of the Ohio had captured a considerable part of this northward drainage prior to the first ice invasion. It may have taken the drainage from as far north as Bellaire, for the glacial gravel there rests on a rock floor that is somewhat lower than the high terraces on tributaries of the Ohio in that vicinity that seem to have been developed by the northward drainage. These terraces are about 1,000 feet above sea level at the borders of the Ohio Valley, while the rock floor under this gravel is about 960 feet. It is thus at practically the same altitude as the bed of the channels near East Liverpool. If then the Ohio ceased flowing southward at the end of the first ice invasion it is suggested that a small southward flowing stream may have occupied the valley below Bellaire and have eventually taken the drainage from as far up as those channels, and later have cut away the col near Smiths Ferry. In that case it furnished no obstruction to the southward flow of the Illinoian glacial drainage from the mouth of the Beaver.

LITTLE BEAVER CREEK

Another feature that suggests a resumption of northward drainage of the Monongahela—Beaver system, and also the Little Beaver, is the low altitude of the rock floor in parts of these old drainage lines inside the glacial boundary, as revealed by borings. In the old channel of the Little Beaver west of Wampum, Pa. a boring is reported to have reached a depth of 300 feet on ground below the 1,040-foot contour without reaching rock. The data were obtained from a neighboring farmer, and given by him from memory, so there may be some question of its reliability. It was noted, however, that in the adjacent part of the Beaver Valley north of Wampum the rock terrace bordering the stream has about 800 feet altitude and the rock floor is a little below 800 feet on the west side of the valley. This is 60 to 100 feet lower than the broad rock terraces on the Beaver near Homewood and Beaver Falls, 10 to 15 miles south, which seem to be the rock floor of the preglacial Monongahela-Beaver drainage. The level is such as to suggest some lowering in interglacial time, and the breadth of the valley to indicate a stream larger than the present Beaver River.

Data collected by Prof. G. F. Lamb in the vicinity of Youngstown, Ohio, lead him to think there is an inner valley of moderate width and depth cut in the preglacial floor of the Monongahela-Beaver drainage.[1] The data also seem to indicate that the drainage was northward toward the Erie basin.

EARLY QUATERNARY NONGLACIAL STREAM DEPOSITS

CARMICHAEL FORMATION

Deposits of early Quaternary age made by streams that do not head within the glaciated district are preserved on high terraces on the borders of their valleys. The highest of these deposits seem to correlate with the oldest glacial gravels on the Allegheny, upper Ohio, and Beaver valleys. Deposits at slightly lower altitude probably correlate with the gravels of Illinoian age. Some of the nonglacial deposits are in abandoned oxbow loops on the borders of the valleys. In some cases the loops seem to have been occupied by the streams down to the Illinoian glacial stage, while others were abandoned earlier. Campbell has applied the name Carmichael formation to these deposits[2] and the name Carmichael clay to the clayey portion, the term being taken from the village of Carmichaels, Pa., which stands in an abandoned loop of the Monongahela River, where the deposits are well preserved. The name Carmichael has been applied by Campbell and other geologists, in other folio publications of western Pennsylvania, to deposits on high terraces on all the streams that do not carry glacial gravel deposits. On the lower terraces and the river bottoms the deposits are termed alluvium.

The tributaries of the Allegheny that drain unglaciated districts are mainly on the east side and their gradients are rather high, so that the aggradation on the Allegheny caused but little change in the character of their deposits. But the Monongahela River throughout its course in Pennsylvania, and the lower part of the Youghiogheny River, have a much lower gradient than the Allegheny. Prior to the aggradation with glacial gravel on the Allegheny these streams were transporting a rather fine sandy gravel in the lower ends of their valleys. But as glacial gravel filled the Allegheny Valley and the Ohio, past the mouth of the Monongahela, it caused ponding in the Monongahela and lower end of the Youghiogheny Valley. In the quiet water then occupying these valleys was deposited a coating of clay or silt. The deposits of clay and silt made at the Illinoian stage are much better preserved than those connected with the earlier glaciation. But deposits that are too high to be connected with the Illinoian ponding are still present on the borders of the valley, and especially in the abandoned loops.

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[1] Personal communication.

[2] Campbell, M. R., Geologic atlas of the United States, Masontown-Uniontown folio, no. 82, pp. 3, 4, 9, 1902.

Morgantown, West Virginia. The southernmost place at which the present writer has observed a clay deposit that seems referable to the early glacial stage is that brought to notice by I. C. White,[1] near Morgantown, W. Va. The deposits farther south at corresponding altitude are of sandy character. Those in the vicinity of Clarksburg and Fairmount have an upper limit at 1,040-1,050 feet. The surface of the clay deposit near Morgantown has been accurately measured by White and found to be 1,035 feet. The altitude is thus very nearly the same as the highest pebbly deposits found in the lower end of the Allegheny Valley, which as above noted reach an altitude of 1,040 feet. The deposit is in an abandoned oxbow loop on the east side of the Monongahela River about 2 miles below Morgantown. Plant remains found in it were identified by F. H. Knowlton and his deductions are included in the paper by White. Ten different species were recognized, among which were oak, white elm, black birch, beech, and sycamore. There was also a water plant, *Potamogeton robbinsii* Oakes, which now is found from New Jersey to New Brunswick, and north of Lake Superior. This was taken to indicate a relatively cold climate at the time the clay was deposited, a matter of importance in correlating it with the early glaciation.

In the paper cited, White gave the name Lake Monongahela to the ponded condition of the Monongahela, and expressed the view that it reached an altitude of about 1,100 feet, and found its discharge westward through passes at that height on the borders of the drainage basin, one of which is near Salem, W. Va. He referred the ponding to the blocking of the old north-flowing Monongahela—Beaver drainage by the ice sheet instead of to aggradation by gravel deposits at the mouth of the present Monongahela River. The interpretation given by White calls for a col higher than 1,100 feet on the present course of the Ohio River below the mouth of Beaver River. But the distribution and coarseness of the early glacial gravel on that part of the Ohio are such as to indicate that the col was not more than 1,000 feet above sea level. Furthermore, clay deposits at the pass near Salem, cited by White in evidence of ponding there to that height, are not due to general ponding, but are in the head of a valley that has been captured by Middle Island Creek, a direct tributary of the Ohio. For these reasons, and because the upper limit of pebbles seems to be not over 1,050 feet in the vicinity of Morgantown, the ponding is placed at about that level, and is referred to the filling at the present mouth of the river. The ponding in the vicinity of Morgantown at the Illinoian stage, as shown by evidence presented later, appears to have caused deposition to a level between 980 and 1,000 feet.

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[1] White, I. C., Origin of the high terrace deposits of the Monongahela River: Am. Geol., vol. 18, pp. 368-379, 1896.

Dilliner and Mapletown. On the west side of the Monongahela, back of Dilliner, Pa., pebbles are strewn over the slope as far up as the 1,040-foot contour, probably as a result of the ponding in the early Quaternary. There is a heavier deposit on the east side between Dilliner and New Geneva, but its upper limit is only 1,000 feet, as mapped by Campbell in the Masontown folio. It probably includes some early Quaternary material, but it has not been differentiated.

Near Mapletown in Greene County, there is an abandoned oxbow loop on the west side of the Monongahela, extending back into the lower end of Whiteley Creek valley, with pebbly deposits up to about 1,040 feet. The filling along the axis of the old channel is deep, but its surface is below 1,000 feet, and it may embrace Illinoian deposits. The deposits above 1,000 feet are deeply weathered and form a thin veneer on the rock formations.

Masontown loop. From the loop just mentioned the old course of the Monongahela was around the Masontown loop on the east side of the river. The filling here reaches an altitude of more than 1,020 feet in the north part of Masontown. The slight exposures in this highest part show a loamy sand of orange color consistent with weathering of an early Quaternary deposit. In only a small part of the loop is the deposit preserved at its full height. The amount of erosion thus supports the interpretation that the loop was filled and then abandoned by the river in early Quaternary time. At the Illinoian stage the ends next to the river had become eroded to a level low enough for the ponding to flood them and make a thin deposit of clay on the eroded surface of the earlier deposit. This is well exposed at a gravel pit on the north side of Big Run. The clay is 5 to 10 feet thick and its surface is between 960 and 980 feet. The rock floor is 30 feet lower. The deposit of sandy gravel under the clay shows deep weathering consistent with early Quaternary age. This being the case it follows that the valley had been cut below 950 feet here in early Quaternary time.

Carmichaels channel. Just below the Masontown loop, at McCanns Ferry, the Monongahela River has been diverted into a new course for a distance of about 6 miles, the old course being past Carmichaels. The south end of the old course is now drained by Little Whiteley Creek, and the north part by Muddy Run and a tributary, Glade Run. The divide in this old course is a little below 1,000 feet in the middle of the valley, but pebbles strew its slopes up to an altitude of more than 1,020 feet, and thus testify to a ponding to that height. The diversion will be accounted for if the ponding was high enough to submerge a pass north of McCanns Ferry. From this pass a more direct drainage line led northward to the north end of the old channel than the old course past Carmichaels, and this was utilized by the river after the ponding stage. The amount of erosion of the deposits in the old channel by the small drainage lines now occupying it, as well as the height to which pebbly deposits are found on the slopes, favor the reference of this diversion to early Quaternary time. To account for this diversion Campbell suggested an ice jam in the part drained by Muddy Run,[1] and cited the scantiness of the deposits and the absence of clay there in support of this view. At the same time, in his discussion of the Carmichaels valley in the later of the publications cited, he states that the rock floor has been considerably dissected by Muddy Run. This is an evidence that the erosion of the silt is a minor matter in comparison with the erosion in the rock floor accomplished by this small stream. Furthermore, it is exceedingly doubtful if ice jams produced by the breaking up of river ice could persist long enough to allow the diverted stream to become intrenched in its new position.

The deposits in the Carmichaels valley are reported by Campbell to have a thickness of 60 to 70 feet where best preserved. The altitude in the village of Carmichaels is above 1,000 feet, and wells there obtain their supplies in sand at about 40 feet. The rock floor near the village is higher than at other points along the old channel. Campbell estimated the rock floor to be as low as 920 feet in the middle of the channel.

The precise method of filling of such channels as this while in a ponded condition is a matter on which further light seems necessary. During the aggradation at the mouth the ponded condition was in process of extension up the valley, and there would be a checking of the flow in parts not yet ponded, and a probable deposition of considerable fine material. During the most complete ponding there was a discharge into the Ohio valley and a gradual movement of the water in that direction, with deposition of more or less fine sediment. The ice floating down the valley in the spring is likely to have dropped pebbles and stones of various sizes on the banks where it chanced to lodge. Then after the aggradation was completed and erosion of the filling on the Ohio had set in, there would be a shortening of the ponded area corresponding to the depth of erosion, and a change to fluvial conditions, with more vigorous transportation of sediment into the valley. Possibly some parts of loops that were indirect courses for the flow of the stream were not graded up to the extent of the direct courses. This is known to have been the case in the lower end of the Allegheny valley in the Illinoian stage, as indicated below. Deposits that were laid down in the early Quaternary are now so greatly eroded by the Monogahela, and by the small streams in the abandoned loops, that it is difficult to determine to what extent the valleys were filled.

East of Rices Landing there is an exceptionally broad, high terrace bordering the Monongahela River, over the highest part of which are strewn rounded cobbles and boulders, resting directly on the rock floor, at an altitude of more than 1,020 feet. Thicker deposits on a lower area on the border of Pumpkin Run, with a rock floor at about 940 feet, may be partly of Illinoian age, but the scattered stones at the high altitude are likely to be early Quaternary deposits.

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[1] Campbell, M. R., Hypothesis to account for the extra-glacial abandoned valleys of the Ohio basin (abst.): Geol. Soc. Am. Bull., vol. 12, p. 462, 1901.
Description of the Masontown and Uniontown quadrangles, U. S. Geol. Survey, Geologic atlas, Masontown-Uniontown folio, no. 82, pp. 3-4, 1902.

Brownsville. In a bend of the Monongahela valley 3 to 4 miles west of Brownsville, gravel and cobble deposits are present on a sloping surface on the north side of the river to an altitude of more than 1,020 feet. The deposits are rather scanty, and the pebbles are deeply weathered to a degree consistent with early Quaternary age. They are immediately west of an abandoned channel of the Monongahela that may have been flooded in Illinoian time, as it carries a deposit of clay above cobbly deposits at about 960 feet.

No deposits were noted farther down the Monongahela valley that come up to the altitude of this just described, the upper limit being generally considerably below 1,000 feet, or within the probable level of Illinoian ponding. It seems natural that most of the material brought in by the river should be deposited near the head of the ponded area. It should also be noted that material brought in by tributaries which enter farther down may not reach the main valley because of the ponding of their lower courses.

Youghiogheny River. On the Youghiogheny, valley deposits that seem to be of early Quaternary age occur as far down as Buena Vista, near the southern edge of the Pittsburgh quadrangle. They are present to an altitude of over 1,000 feet opposite Buena Vista, on the east side of the valley. A few miles farther up, near Port Royal, deposits carrying scattered cobbles cover a broad terrace west of the river that is above 1,020 feet. Deposits occur to similar height at Perryopolis, and at other points between there and the base of Chestnut Ridge at Connellsville. This part of the Youghiogheny thus seems to have been affected by early Quaternary ponding as was the Monongahela valley between Morgantown and Brownsville.

THE ILLINOIAN DRIFT

DISTRIBUTION

The presence of glacial deposits outside the Wisconsin terminal moraine in northwestern Pennsylvania has been recognized from about the time of the tracing of the moraine by H. C. Lewis and G. F. Wright in 1881, but there has been wide difference of opinion among geologists as to the age of these deposits. Lewis and Wright regarded them as of the same glacial stage as the moraine, and due to a temporary extension of the ice sheet beyond the moraine. The outlying deposits were called "the Fringe." But other geologists, including T. C. Chamberlin and the present writer, have noted evidence that the deposits are of markedly greater age than the moraine, and have referred them to a distinct ice invasion. In an earlier publication[1] the present writer interpreted them to be at least as old as the deposits of Kansan drift of the north Central States, which is referred to the second glacial stage. Recent studies, however, have led to the opinion that the deposits correlate more closely with the Illinoian drift, the product of the third glacial stage. In the till, as well as in the gravel outwash, many of the pebbles exhibit only a moderate degree of etching and weathering, and the till seems not to have suffered a great amount of erosion.

The earlier interpretation, that this drift is older than Illinoian, was based mainly on the amount of erosion in the lower Allegheny and upper Ohio valleys between the deposition of its outwash or valley train and that of the Wisconsin drift. Proper consideration was not given to the effect of so great an enlargement as the Allegheny River had experienced, and to the rather high gradient and swift current of the enlarged stream. The fact had been noted in the earlier studies that deepening of the tributaries of the lower Allegheny had only had time to extend a few miles up from their mouths, but this seemed less impressive than the erosion displayed by the main stream. The deepening subsequent to the deposition of the valley train involves not only the removal of a considerable part of the filling, but in addition a trenching in rock of about 200 feet in the part below the mouth of Clarion River, and a similar depth on the Ohio in western Pennsylvania and along the Panhandle of West Virginia. It has since been found that the post-Illinoian trenching has been very moderate farther down the Ohio. This restricts the main post-Illinoian trenching in rock to the middle and lower Allegheny and a relatively short section of the Ohio valley.

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[1] Monograph XLI, U. S. Geol. Survey, 1902.

The recent studies have led to the conclusion that the rather scanty deposits of drift found for a few miles outside the moraine in Beaver and Lawrence counties, and as far north in Butler County as the vicinity of Slippery Rock village, are referable to the Wisconsin stage of glaciation rather than the Illinoian, for in places the drift takes on the sharp hummocky topography characteristic of the Wisconsin drift. It also shows only a moderate depth of oxidation, blue till being found in places at only 10 to 15 feet. The Illinoian drift is oxidized to a rusty brown or an orange color, whereas this outlying drift has a yellowish brown color like that commonly displayed by the Wisconsin drift.

The Illinoian drift is exposed in a strip only 2 or 3 miles wide in northwestern Butler County. It widens to 6 or 8 miles in southern Venango County, in the district lying between Clintonville and Wesley. The border lies along the west bluff of the Allegheny northward from Kennerdell to the vicinity of Franklin. It may cross to the east side of the river for a few miles opposite Franklin and Reno, though as previously noted it is quite probable that the drift there is pre-Illinoian. The border appears to lie west of Oil Creek for a few miles north of Oil City, but crosses to the east side between Rouseville and Petroleum Center. It takes a northeastward course from Oil Creek valley past Pleasantville in Warren County, touching the northwest corner of Forest County. The border there turns northward, and passing about 3 miles west of Tidioute it covers the headwaters of Tidioute Creek. It follows the southeast side of Brokenstraw valley about to Youngsville, then crosses to the north side and continues eastward on the north side of the Allegheny River to North Warren. Then crossing Conewango valley it takes a northward course into New York, at a distance of 2 to 4 miles from the creek. From Russell, Pa. northward the Wisconsin deposits also are present on the east side of this valley, and they appear to cover completely the Illinoian deposits from near the State line northeastward in Cattaraugus County, New York. The Illinoian border, however, is likely to lie but a short distance back from the Wisconsin limit, for outwash from it is found in the Allegheny valley as far up as Red House, N. Y.

The greatest width of exposure of the Illinoian drift in northwestern Pennsylvania is only about 15 miles, and there are places where it is less than 5 miles. The length of the exposed strip, from Slippery Rock, Pa. to the New York line is about 85 miles. The average width of exposure is about 10 miles, thus giving an exposed area of about 850 square miles.

THICKNESS OF THE DRIFT

The Illinoian drift is a rather thin deposit on uplands, usually between 5 and 15 feet, but in valleys there are in places more than 100 feet of till and other deposits. The sheet of till is generally so nearly continuous as to be mapped without difficulty to within a mile or two of its limits. It thus differes from the Kansan drift of the north Central States, for its limits can seldom be fixed within a space of several miles. The original thickness of the till on uplands in northwestern Pennsylvania may have been a few feet more than at present, but it is doubtful if it was twice as thick. One of the most surprising features of the Illinoian deposits of this district is the thinness of the till compared to the great volume of the valley trains of gravel connected with it. The valley trains are not only much thicker than the till but they extend for a great distance down the valleys, as indicated below.

CHARACTER OF THE DRIFT

The Illinoian drift shows markedly deeper oxidation than the Wisconsin, and its surface boulders are much more weathered. Exposures are entirely in an oxidized deposit, even where 30 feet or more in depth. The till is generally rather loose textured and stony, a condition that favors easy penetration by water, especially in situations high above the level of the drainage lines. In some places cobblestones and boulders make up the main part of the deposit, and that too where stratification is not apparent. Where streams led away from the ice border the drift in places passes gradually from a stony till into definitely assorted material. At Pleasantville some wells in the headwaters of Pithole Creek, and near the Illinoian limits, show about 80 feet of drift, characterized as gravelly by the well drillers.

The surface of the drift shows considerable variation in the number of boulders. There are wide areas in which they are rather scarce, while in other areas they are a conspicuous feature. They are usually of small size, rarely as much as 3 feet in diameter, and commonly 1 to 1½ feet or less. Granite boulders and pebbles of Canadian derivation are not rare, and they also constitute a notable element in the outwash gravel and valley trains. The rocks embedded in the drift are largely local, or from near by districts, but rocks of Canadian derivation are not an uncommon feature. They include greenstones of several kinds as well as granite and gneiss.

On the upland west of Oil Creek about a mile south of Titusville is the only kame noted in the Illinoian drift of northwestern Pennsylvania. It stands east of the highway leading from Titusville to Oil City, at an altitude of about 1,500 feet, or 350 feet above Oil Creek. The knoll is 60 rods in longest diameter, and has a height of 20 to 25 feet. A large gravel pit has been opened in it, and a considerable part of the knoll has already been removed. It appears to be almost entirely of gravel suitable for use on roads.

Most of the exposures of this drift are in the cuts along the main highways, and these are usually only 5 to 10 feet in depth. They serve, however, to show that the drift is generally of unassorted material. They also indicate whether the drift is a continuous sheet, or of a patchy character. Thus the highways radiating from Pleasantville indicate that the till is a practically continuous sheet to within about a mile of its limits. Instead of a thickening of terminal moraine at the border there is a change to a patchy deposit at about a mile from the border.

ILLINOIAN GLACIAL DRAINAGE

As the Illinoian ice border stood near the Allegheny valley from Steamburg, N. Y. to Kennerdell, Pa., that valley was in a favorable situation to receive the outwash and carry it as a valley train beyond the ice limits. It probably received deposits at Steamburg, N. Y., where the ice border crossed the old north-flowing upper Allegheny, at Warren, Pa. from Conewango Creek, at Irvine from Brokenstraw Creek, at Tidioute from Tiodioute Creek, and at points below Tidioute from Hickory and Pithole creeks, at Oil City from Oil Creek, at Franklin from French Creek, at Brandon from West Sandy Creek, and at Kennerdell from Scrubgrass Creek. Below Kennerdell there was a long stretch, extending to the mouth of Beaver River in which no glacial gravel was brought in by tributaries of the Allegheny and Ohio rivers, but there was an important accession at the Beaver valley. Probably some material was brought in by the Little Beaver. There was then another long stretch without accessions, reaching to the mouth of the Muskingum River, at Marietta, Ohio. The Muskingum, Hocking, and Scioto rivers each brought in glacial material. The Little Miami and Great Miami became contributors as the ice border melted back past their mouths. At the greatest extent of the Illinoian ice sheet the Ohio valley was covered for some distance above and below the mouths of these streams, and this probably produced a temporary ponding above the part thus covered. But the presence of an Illinoian gravel train in the Scioto valley indicates free drainage down that valley during part of the Illinoian glacial stage.

ALTITUDE OF FILLING IN ALLEGHENY VALLEY

The Illinoian filling in the Allegheny valley in the vicinity of Steamburg, N. Y. reaches an altitude of 1,460 to 1,480 feet. At the line of New York and Pennsylvania it is about 1,420 feet, at Warren, Pa. 1,380 feet, near Tidioute 1,280 to 1,300 feet, and at Oil City about 1,240 feet. It is nearly 1,200 feet at Brandon and at Kennerdell. There is thus a continuous descent in the gravel train along the part of the Allegheny valley closely bordered by the ice sheet, and there seems to have been very little ponding in the valley at this glacial stage. The col east of Warren and that above Tidioute seem to have been trenched to a level low enough to allow free drainage, and so also were the cols above the mouth of West Sandy Creek, and above the mouth of the Clarion River. The altitude of the Illinoian gravel filling near the mouth of the Clarion is about 1,150 feet. It drops to 1,080 feet at the mouth of Redbank Creek and 1,040 feet near the mouth of the Kiskiminetas River. It falls below 1,020 feet near Natrona Heights, and is between 1,000 and 1,020 feet from there to the mouth of the Allegheny. It is about 960 feet near the mouth of Beaver River, and but little above 900 feet at East Liverpool, Ohio, near the mouth of the Little Beaver. The col near Smiths Ferry seems to have been cut to a level of 900 feet or less at the time of the Illinoian filling. The Illinoian filling is about 800 feet at Moundsville, W. Va. and 700 feet in the vicinity of Parkersburg. The Ohio valley below Parkersburg appears to have been cut to nearly its full depth prior to the Illinoian glacial stage.

The data on the altitude of the Illinoian glacial gravel train pertain to the deposits on the line of main drainage down the Allegheny valley. It is found that the deposits are somewhat higher there than in indirect channels on the border of the valley. In the abandoned loop opposite Parkers Landing the deposits scarcely reach 1,120 feet, but in the main valley just south of Parkers Landing, at the mouth of Bear Creek, they are above 1,140 feet, and also 3 miles down the Allegheny valley, at Monterey. There is another abandoned loop in the west part of the Freeport quadrangle running from Chartiers Run to Little Pucketa Creek in which the deposits are about 980 feet and largely clay. In the main channel, northeast of New Kensington, they are above 1,000 feet. At Springdale the deposits in the main channel reach 1,000 feet, but in a recess on the north side of the river west of Springdale, that embraces the lower end of Deer Creek valley (Fig. 38) they only reach about 970 feet. Another loop in the south part of the New Kensington quadrangle, drained by Powers Run and Squaw Run, is filled to only about 960 feet. Gravel was carried but a short distance into it, the main part of the loop being filled with clay deposits. In the north part of the Pittsburgh quadrangle, a loop on the south side of the Allegheny, drained in part by Sandy Creek, was filled to about 960 feet with clayey deposits. A channel on the north side of the Allegheny, leading from Etna to Millvale, back of a range of hills fronting on the river, has been filled to less than 940 feet with clayey deposits. The level of the water in these indirect channels was up to the same height as in the main channel opposite each of them, but the current was too weak to carry coarse material. The height of the filling was but little greater than in the ponded water of the lower end of the Monongahela valley.

There seems also to have been difference in the height of filling along the main channel to correspond to the windings of the stream, the deposition being to greater height on the inner curve than elsewhere and more nearly up to the level of the surface of the stream. The places where filling in the New Kensington, Pittsburgh, and Carnegie quadrangles is up to 1,000 feet are at the inner curves. It is not improbable that the filling on the outer curves was 30 feet or more below this level. The average level of filling in this part of the Allegheny valley may not have been more than 970 feet. The rock floor in this part is not far from 900 feet. It thus appears that although there are places where the surface of the gravel is more than 100 feet above the level of the rock floor the average filling on the main channel may not have been more than 70 feet. A study of the topographic maps has also made clear that the average breadth of the Allegheny valley at the level of the top of the gravel filling is not more than three-fourths of a mile. At the level of the rock floor it is less than two-thirds of a mile. It seems a liberal estimate to give the Illinoian de-

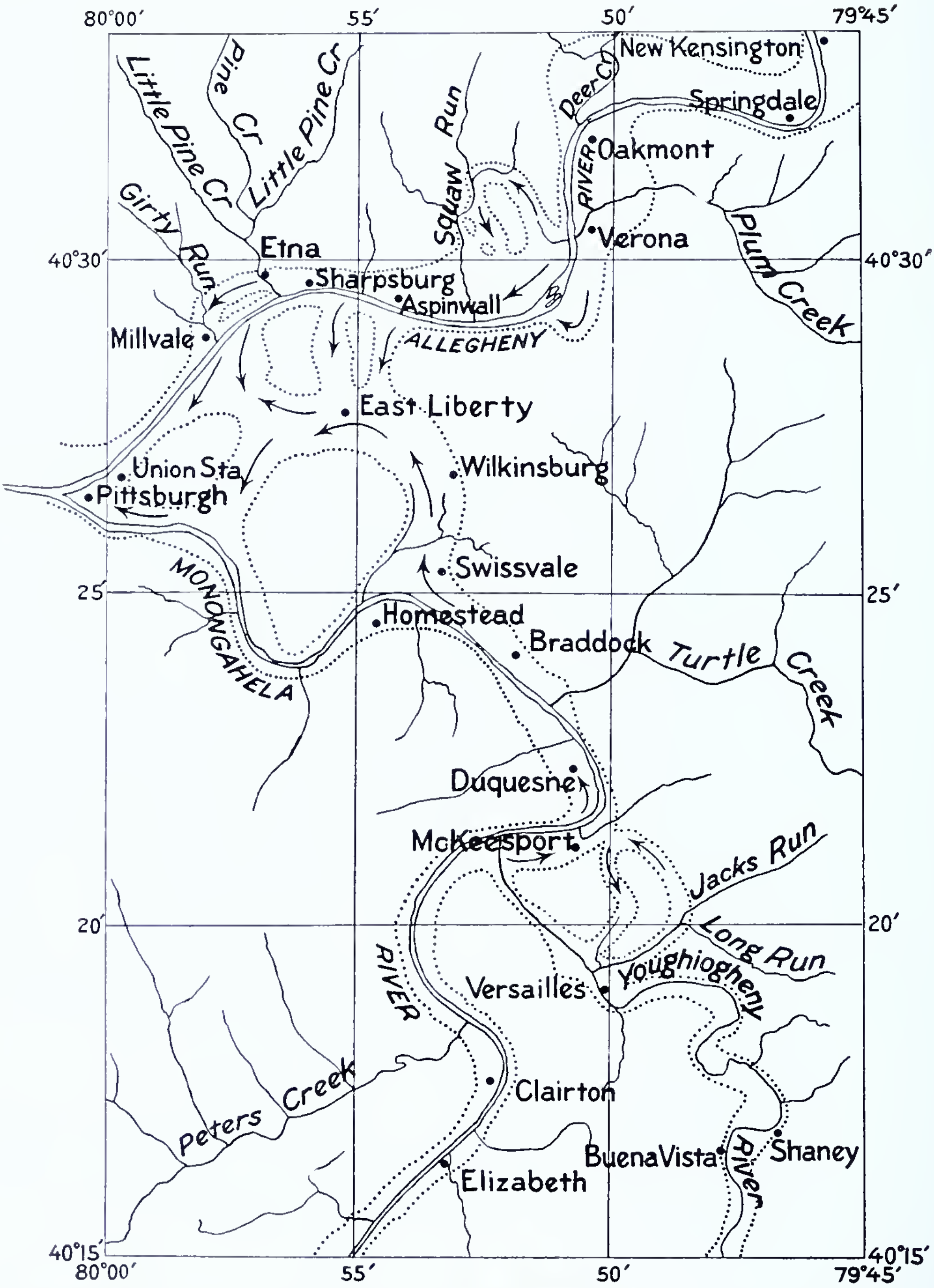

Figure 38. Old channels and high-level terraces on the lower ends of Monongahela, Youghiogheny, and Allegheny Valleys.

posits a depth of 70 feet and width of seven-tenths of a mile in the part of the valley below Kennerdell, where the stream was entirely outside the limits of the Illinoian ice sheet. In the Ohio valley in Pennsylvania there was probably a similar depth of filling and an average width of somewhat less than a mile. After passing out of Pennsylvania the Ohio valley seems to have been only slightly aggraded with Illinoian gravel, so far as can be determined from the deposits still remaining in it.

In the Allegheny valley between the mouth of Brokenstraw Creek and the mouth of Clarion River it is difficult to estimate the amount of filling with glacial gravel. The valley is narrow and remnants of the gravel are more scanty than in the part below the mouth of the Clarion. It is also difficult to identify the old rock floor on which the gravel was deposited as the rock shelves are narrow and ill defined. There seems also to have been considerable redeposition of the gravel at lower levels than the original deposit in the course of the valley deepening.

Between the mouth of Brokenstraw Creek and the place where the old Tionesta came to the Allegheny valley, east of Warren, the old rock floor is a little below the present valley bottoms, but the Illinoian gravel filling reaches a level about 200 feet above the river. This may embrace considerable pre-Illinoian gravel, but there is also a heavy deposit of Illinoian age. There is a similar condition in the Allegheny valley near Steamburg, N. Y., with a rock floor below the present stream and deposits reaching a height of about 200 feet above the river. Much of this deposit seems to have been laid down in the Illinoian stage.

CRITERIA FOR AGE OF DEPOSITS

In the earlier studies in the 1890s the writer was impressed with the great amount of erosion which had taken place in the lower Allegheny and upper Ohio valleys between the deposition of the gravel under discussion and the gravel train of Wisconsin age. It seemed sufficient to warrant referring these deposits to early Quaternary time. It was also noted that these deposits have a rusty and weathered appearance decidedly in contrast with the fresh gray gravel of the Wisconsin stage. In the recent studies between 1925 and 1929 it has been found that a considerable part of the erosion on the Ohio below Wheeling, W. Va. had been accomplished before the Illinoian stage of glaciation, thus greatly reducing the amount that had been assumed to have taken place subsequent to the deposition of the gravel. It has also been found that the till outside the Wisconsin border in northwestern Pennsylvania has suffered much less erosion than had been previously supposed, an amount more nearly in keeping with that of the Illinoian drift of States to the west than with that of the Kansan drift. A study of the pebbles in this gravel, especially the granite and gneiss pebbles, has shown that many of them still present a polished surface decidedly in contrast with the etched and deeply weathered surface of the same kinds of pebbles found in the early Quaternary gravels of this region, above described. In view of all these conditions the writer now refers these gravels and the till with which they are connected with some confidence to the Illinoian stage of glaciation, instead of the Kansan or pre-Kansan, as interpreted in earlier writings.

To what extent the trenching of the lower Allegheny and upper Ohio valleys is due to the enlargement of the drainage area, and to what extent to uplift, is a matter on which the geologists who have worked in this region differ in opinion. The present writer favors drainage enlargement as the main factor, especially since no collateral evidence has been cited in support of a post-Illinoian uplift in this region.

ILLINOIAN PONDING IN THE MONONGAHELA BASIN

From the data above given it appears that at times the Illinoian water level at the junction of the Allegheny and Monongahela rivers was fully 1,000 feet. At low water stages it may have been 30 feet lower at the time of the completion of the filling with glacial gravel. If there has been no differential uplift the ponding on the Monongahela is likely to have had influence as far up as Morgantown, W. Va. There is a filling on the borders of the valley at that city with a surface altitude slightly below 1,000 feet that may be referable to the Illinoian ponding. The deposits, as shown by wells, are about 70 feet thick and rest on a rock floor at about 920 feet. Three miles below Morgantown, and half a mile north of Star City, pits have been opened for sand and clay in a terrace at 980 feet elevation. The deposits here exposed show an interesting alternation of sandy and clayey beds that seem consistent with such changes in water level as probably occurred at the mouth of the river at the high water and low water stages. When the water level there was high this terrace would be covered with ponded water, but at low stages the water would recede and the river would be free to spread sand over the terrace. The clay beds are thinner than the sand beds, being in some cases only 1 to 2 inches thick, while the sand beds are usually several inches thick.

The level of the main silt deposits in the lower end of the Monongahela valley, near McKeesport, and in the East Liberty channel, is about 940 feet. The river deposits under the silt reach about 920 feet. The rock floor is about 900 feet in this part of the valley and seems to be nowhere lower than 880 feet. There is thus surprisingly little grade in the rock floor between Morgantown and the mouth of the river. It is much less than the fall of the present stream, which is 103 feet, or from 800 to 697 feet. The present stream is also more direct in its course than the one that was flowing on this old valley floor. While the water surface in the ponded area was level the silt was mainly deposited in the valley bottoms, and its altitude declines with them toward the mouth of the stream. The scanty deposit of silt deposited on the slopes above the old river bed has probably been entirely removed by the erosion or wash on the steeply inclined surface. The deposition on the valley bottoms was probably heavier near the head of the ponded area than in the lower end of the valley.

Deposits in Greene County. As noted in the discussion of the early Quaternary deposits, there may be Illinoian silts along the axis of the abandoned loop near the lower end of Whiteley Creek to an altitude of 980 feet, and in the west end of the Masontown loop to over 960 feet, and perhaps also in the Carmichaels channel to about 980 feet. The deposits back of New Geneva reach 1,000 feet, but the rock floor beneath them as determined by I. C. White[1] is only 912 feet. That the valley had been cut to so low a level in early Quaternary time has not been clearly established, but evidently by the Illinoian stage it was cut to this level. The deposits here are described by White to be boulders, sand, and river trash for 55 feet, below which they are mainly clay for 16 feet, to the rock floor. The top of the deposits at the place measured by White is 983 feet above sea level, which is within the probable limits of the Illinoian ponding. There may be Illinoian deposits fronting on the river, and early Quaternary deposits farther back, where the altitude is above 1,000 feet.

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[1] White, I. C., Origin of the high terrace deposits of the Monongahela River: Am. Geol., vol. 18, p. 373, 1896.

At the mouth of Tenmile Creek there are deposits of clay, carrying a few cobblestones, with a surface altitude estimated to be 960 feet, which are presumably of Illinoian age. Clay including cobblestones covers a terrace near Riverville at 960 feet, and a similar deposit with about the same altitude is exposed in the abandoned channel on the north side of the Monongahela River 3 miles west of Brownsville. There is also a cobbly clay 15 to 20 feet thick in the village of California on a terrace at 960 feet, which probably is Illinoian.

Deposit near Fayette City. In an abandoned loop southeast of Fayette City, now drained by Little Redstone Creek, the clay filling in the axis of the valley is between 940 and 960 feet and the deposit in places is 15 feet or more thick. But in the middle of the north limb of the oxbow a road exposure shows 6 to 8 feet of clay resting on a black soil which was formed on the underlying river deposit of sandy gravel prior to the ponding that laid down the clay. This loop may thus have been abandoned by the river before the Illinoian ponding took place, and then have been flooded during that ponding. The rock floor of this old oxbow seems to be but little if any above 900 feet, and in harmony with the main high-level terrace bordering the Monongahela.

Between Fayette City and Belle Vernon there are two abandoned channels east of the present Monongahela Valley. They do not form as complete an oxbow loop as the channel drained by Little Redstone Creek. They may have been cut contemporaneously with the valley still occupied by the river. The eastern one is somewhat narrower than the present valley, thus favoring the view that it carried only part of the flow of the river. Both of the channels have a rock floor at about 900 feet, in harmony with the main high-level terrace bordering the river. There is thus no evidence in the level of the rock floor to indicate that the eastern channel was abandoned earlier than the western one. The sandy fluvial material in each of them is covered with a few feet of cobbly clay that appears to have been laid down during a ponding of the channels. Its surface is at about 940 feet, or low enough to be consistent with Illinoian age. The abandonment of these channels seems to be due to the river having become restricted to its most direct channel as a steeper gradient was developed by the trenching in the lower end of the valley.

Belle Vernon to McKeesport. Deposits of cobbly clay about 20 feet thick are preserved on the west side of the Monongahela River opposite Belle Vernon at a level similar to that in the abandoned channels east of the river, 920 to 940 feet. The sandy fluvial material under the clay carries a remarkable number of iron seams or flakes, separating the layers of sand. Its appearance is such as to suggest greater age than the Illinoian stage, but the overlying clay seems to be referable to the Illinoian ponding.

From Belle Vernon down to McKeesport the high-level terraces along the Monongahela Valley carry only scattered pebbles and a few thin patches of sandy gravel, the greater part of the deposits having been carried away in the course of the post-Illinoian erosion of the valley.

In the northeast part of McKeesport the Monongahela River has cut into the north part of an abandoned oxbow channel of the Youghiogheny River, which came from Versailles northward along Long Run to the mouth of Jacks Run and then looped around through the eastern part of McKeesport and returned to Versailles, as indicated in Figure 38. In the part of the loop northwest from the mouth of Jacks Run the fluvial material is largely covered by a clay deposit that seems referable to ponding in the Illinoian stage. In the remainder of the loop only a small part of the fluvial deposit and still less of the ponded water deposit has escaped erosion. The extent of the part preserved is well shown in the recent map by M. E. Johnson, Plate II, of his report on the Pittsburgh quadrangle.[1] In this report Johnson interpreted the loop to be the product of the Youghiogheny River. This loop probably was abandoned considerably earlier than the Illinoian ponding for the Monongahela seems to have cut across its northern end prior to this ponding, and mingled its fluvial deposits with those left by the Youghiogheny River. These deposits are on a high-level terrace at 900 to 920 feet. The clay deposits reach the 940-foot level, and are about 20 feet thick where best preserved.

East Liberty channel. One of the most conspicuous of the abandoned channels of the Monongahela River is the "East Liberty channel" in the city of Pittsburgh shown in Figure 38. This leaves the river at Homestead and passes northward through Swissvale and Edgewood to East Liberty, then swings westward and soon branches, one branch turning southward passes between Schenley Park and Oakland cemetery to the Monongahela, and the other continues westward past Allegheny cemetery to the Allegheny Valley. Along much of its course this old channel carries river rubble and sandy material brought in by the Monongahela River, over which there is a clay deposit laid down in ponded water. But the branch which leads to the Allegheny Valley has received a deposit of glacial gravel in its west end, brought there by the Allegheny River. The Allegheny waters also came into the East Liberty channel through two gaps in the hills that lie between it and that river, now drained by Haights Run and Negley Run, leaving glacial gravel in these gaps, but not carrying it far into the ponded water in this old channel. The glacial gravel was built up to a somewhat higher altitude than the general surface of the clay filling in the old channel, being 970 to 975 feet, while the clay filling is about 940 feet. The rock floor of this old channel appears to stand between 880 and 900 feet, or fully 200 feet higher than the rock floor under the present streams at the junction of the Monongahela and Allegheny Rivers and head of the Ohio. Although carrying clay deposits of Illinoian age it may have been abandoned by the Monongahela River prior to that glacial stage.

The East Liberty channel does not make a complete oxbow loop, but comes back to the Monongahela 3 to 4 miles below the place of diversion. The history of the intervening section of the Monongahela has not as yet been clearly worked out. Its narrowness just below Homestead is such as to suggest the crossing of a col, and the breadth of the abandoned valley seems great enough to have taken the entire flow of the river. But the branching of the abandoned valley west of East Liberty suggests the possibility that there was a similar branching at Homestead, in which case the river has not been diverted into a new course, but has become restricted to one branch of a double channel. If there has been a diversion to a new course it remains to be determined whether this was due to aggradation to a height sufficient to reach the level of a col below Homestead, or whether a capture was effected by a branch of Streets Run, which comes into the river just below the narrows. The branching channels of the lower end of the Allegheny River are also involved in a proper interpretation of the drainage history. The district in and around Pittsburgh seems to have become so deeply dissected along certain lines that both rivers were easily shifted in their courses, or were flowing in divided courses around the higher tracts that now overlook these channels.

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[1] Topographic and Geologic Atlas of Pennsylvania, No. 27, Pa. Geol. Survey, Fourth Series, 1928.

A few molluscan shells of fluviatile species were collected by the late Dr. A. E. Ortmann from the deposits in the East Liberty Valley and left in the Carnegie Museum, with which he was connected. So far as the writer is aware this is the only instance of the finding of animal remains in the deposits on these high-level channels.

WISCONSIN GLACIAL DEPOSITS

The recent studies of the Wisconsin glacial deposits in northwestern Pennsylvania and eastern Ohio have led to the conclusion that the ice sheet held a position near the Wisconsin drift limits down to the middle of the Wisconsin glacial stage, and that very little early Wisconsin drift is exposed. Perhaps the scanty deposits in Lawrence County, Pennsylvania, outside the well-defined moraine are of early Wisconsin age. The moraines have a sharpness of expression that seems indicative of later age than early Wisconsin. The early Wisconsin moraines, as exposed from central Ohio westward into Illinois, exhibit a marked toning down of the knolls, such as does not characterize the knolls of this district. It appears that the ice sheet continued to hold its full limits in this district south of the Lake Erie Basin after it had shrunk considerably in Illinois, Indiana, and western Ohio.

The gravel trains connecting with the Wisconsin moraines show that vigorous drainage was operating in nearly all the valleys that drain away from the Wisconsin ice border. The deposits are especially coarse on the Beaver River, there being boulders in them up to 2 or 3 feet in diameter at Beaver Falls, and 1½ feet in diameter at the mouth of the river, at Beaver. Granite rocks up to 10 inches in diameter have been noted as far down the Ohio as New Matamoras, Ohio. This is 100 miles below the mouth of Little Beaver Creek, the nearest contributor of glacial gravel, and 115 miles below the mouth of Beaver River, the main contributor. There is a long section of the Allegheny below the mouth of French Creek and 25 miles of the Ohio Valley that was entirely free from streams that headed within the Wisconsin drift, yet there is a continuous train of glacial gravel in this section. This section, however, probably received considerable glacial gravel from the Illinoian gravel deposits along it, in the course of the erosion of the valley in pre-Wisconsin time. Possibly the accessions from this source were greater than from the Wisconsin glacial drainage.

On most of the Allegheny and its tributaries above the mouth of French Creek the upper limit of the Wisconsin gravel train is only about 50 feet above the level of the present streams, but in the French Creek valley it reaches nearly 100 feet, and at the mouth of the Beaver fully 130 feet above the stream. The low water level of the present Allegheny and Ohio rivers is generally 30 to 40 feet above the rock bed in these valleys, and the valleys appear to have been cut to their full depth before the Wisconsin glacial stage, for the Wisconsin gravel extends below river level under the terraces that border the streams.

Where streams came down to the ice border from higher land outside, as was the case with the Connoquenessing Creek, and with Muddy Creek in Butler County, there was some ponding in their lower courses, as shown by the deposits of clay beneath the valley bottoms. There is, however, a light deposit of glacial gravel on the Connoquenessing below the mouth of Slippery Rock Creek, brought in by that stream.

The Wisconsin gravel has a fresh gray color to within a few feet of the surface that contrasts strikingly with the rusty Illinoian gravel. Most of the pebbles retain the polished surface, where embedded in the terrace deposits, and are nearly as fresh in appearance as those being worked by the present streams.

There are but few places where the glacial gravel is now preserved at its full height, for the large streams in the Allegheny and Ohio valleys spread over the greater part of their bottom lands at flood stages, and have been doing so since they began cutting into this Wisconsin gravel train.

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